The Lens

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THE LENS

A Practical Guide to the Choice, Use, and Testing of Photographic Objectives

BY

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(JOINT-EDITOR OF *THE PHOTOGRAM*)

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PREFACE.

The aim of this book is twofold—to explain the properties of the photographic lens without the aid of mathematical formulæ, and to give instruction in the selection and proper use of a lens. Chapters I. to VII. are devoted to the first of these objects, and are modelled on the lines of that excellent text book, *Photographische Optik*, by Dr. Adolf Miethe, of which, unfortunately, there is no English translation. Chapters VIII. to XVII. concern the practical use of the lens, but should be studied in connection with the first part of the book. Other works on photographic optics, to which the student is referred, and to which, as he will see, the authors are considerably indebted, are as follows:—*The Technics of the Hand-Camera*, by W. B. Coventry, M.Inst.C.E., which contains a specially commendable treatment of "depth of focus"; *Contributions to Photographic Optics*, by Otto Lummer, translated and augmented by Silvanus P. Thompson, F.R.S., which gives the best account of the services of Jena glass in photographic optics; and *Telephotography*, by T. R. Dallmeyer; *Practical Notes on Telephotography*, by R. & J. Beck, Ltd.; and *A Monograph on the Nature and Application of the Telephotographic Objective*, by Dr. P. Rudolph, all of which amplify what is here said on telephotography; Mr. Dallmeyer's work being an exhaustive treatise.

Thanks are here tendered to several persons and firms for the use of blocks, viz., to R. & J. Beck, Ltd. (for fig. 10); J. H. Dallmeyer, Ltd. (fig. 63); Ross, Ltd. (figs. 73, 74, and 75); Carl Zeiss (fig. 109); W. Thomas (figs. 114 and 115); and Miss Evelyn Boden (fig. 117). Professor F. J. Allen has permitted the reprint of the notes on angle of view, and has contributed some others, and Mrs. Catharine Weed Ward has supplied the illustrations on pp. 109 and 110.

London, *April* 1902.

THE Photogram

CONTENTS.

THE LENS.

CHAPTER I.

HOW THE LENS FORMS AN IMAGE, ETC.

[1 *How a Lens works.*—Let us bear in mind that a lens or a pinhole —for we are going to use a pinhole to help us to understand the lens —does not "form" the image we see on the ground glass. The rays of light from the object do that. The lens sifts or alters these rays, permitting a few to do what many could not. First of all let us get a clear idea of what is happening when a camera is set up before, say, a landscape.

The objects in the landscape are lighted by the sun. They are visible to us because they reflect the sun's light to our eyes—*always in straight lines.* In text-books on light you will learn that light follows a certain law when it is reflected—viz., that the angle of incidence equals the angle of reflection (*i.e.* in fig. 1 dotted angle on

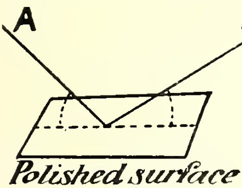

Fig. 1.

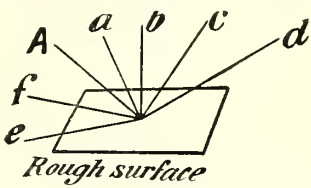

Fig. 2.

right equals dotted angle on left)—but this is true only of polished surfaces like mirrors, metals, etc. If all objects in nature reflected light according to this optical law, we should see things only when they were in certain positions, just as we see the brilliant reflections from a sunlit piece of glass on a wall or from the spangles on a ballet

girl's dress only when we are just in one particular place. But the law is not true for dull surfaced things—the things which make up almost the whole of every subject. These, when a ray of light falls upon them, do not reflect it at one particular angle but scatter it in all directions (see fig. 2), where A is the direct ray of light, and *a b c*, etc., the reflected rays.

Now let us picture this scattering shown in fig. 2 as going on everywhere where light falls. Let us consider it "point by point," and let us think of a point for the moment as Euclid docs, viz., "that which has no size but only position." In fig. 3, *a* and *b* are two such points in a tree. Rays of light fall upon them and are scattered in all

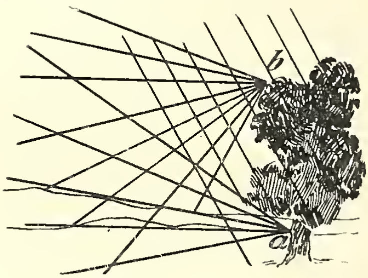

FIG. 3.

directions. What is here shown at *a* and *b* is true of every other point in the tree—of every other point in everything else. It would confuse us to try to represent this complex reflection of light on paper, but let us take one point (*a*, fig. 4) and see what happens when we

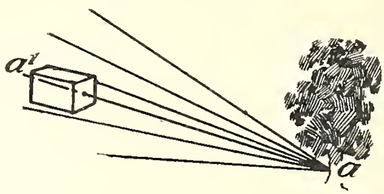

FIG. 4.

place a pinhole camera before the tree. We will assume, what cannot be very well shown in the drawing, that the camera is a long way off.

Of the rays which are scattered from *a*, many will fall upon the camera front, and we can imagine some few (or indeed only one, if we have an exceedingly fine pinhole) passing through the pinhole and

producing an image of the point a at a'. Similarly the point b has its image produced at b' (fig. 5), and this point-for-point formation holds good for every bit of detail in the picture. Figs. 4 and 5 will at once make clear why the image of the whole object is upside down.

Now an image made up of points each of which has no size, is unthinkable, and indeed you will see that the image is really made up of a great number of little discs each the size of the pinhole and each representing, not our theoretical and impossible ray of light, but a little bundle of such rays proceeding from a certain small area. The diameter of each of these little discs determines the "sharpness" or otherwise of the picture—of which more when we come to lenses and "circles of confusion,"—but we can visualise the above "point-for-point" formation of the image by imagining a drawing done not in

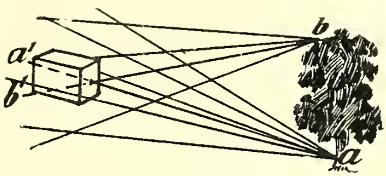

FIG. 5.

line or wash but built up of discs of paper of various shades (*e.g.* confetti). Suppose this "drawing" reduced in size so that the discs are invisible to the naked eye (at a short distance), and we get some idea of the structure of the pinhole image. Let us bear these facts about the pinhole in mind while we go to learn something about the lens. We shall want them.

Try this experiment. Place a coin at the bottom of a basin and take your seat so that the coin is just out of sight (fig. 6). Now get a friend to fill the basin with water. Without having moved your head you will see the coin. Why is this? It is because light, although travelling always in straight lines, is bent in its course when it passes *at an angle* from one substance into another of different density, in this case from water into air. When the direction of the ray is at right angles to the surface bounding the two substances (*e.g.* the line $x\ y$) there is no "refraction."

[2] *A prism* is a familiar refracting instrument and will lead us up to the action of a lens. Fig. 7 shows a prism in perspective and in section. A ray of light falling upon a prism is twice bent (a and b) towards the base. This is, of course, equally true of the prism shown

in fig. 8, or of those (sections of a triangular prism) in fig. 9, however finely the prism may be sliced up. A prism does more than refract a ray of light: it "disperses" it; but we will consider this later. If we place two identical prisms base to base we find that rays of light (a b) are bent similarly and meet at 1; c and d meet

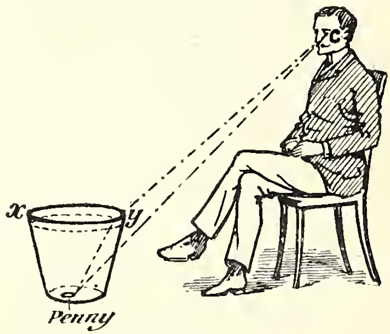

FIG. 6.

at 2; and e and f at 3 (fig. 10). Now imagine each of these prisms sliced up into a great number of very thin prisms; we can imagine each replaced by a prism of slightly different angle such as we get in fig. 11, which is a lens, and owing to its curved surface

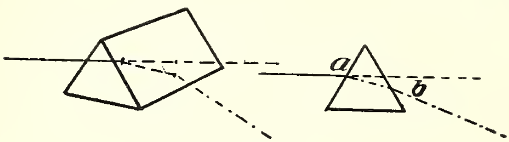

FIG. 7.

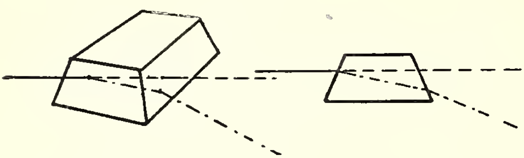

FIG. 8.

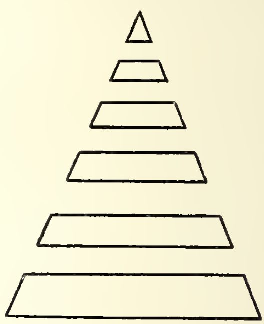

FIG. 9.

bends all rays to the same point. It is a converging or positive lens. If the two prisms are placed apex to apex (fig. 12) we get a lens as in fig. 13, which bends rays further apart instead of bringing them together. It is a "negative" lens.

Now look back to figs. 4 and 5, where it is seen that only a few rays from a given point pass through the pinhole to form the image.

Imagine the pinhole replaced by the lens. A much larger number of rays from each point are now received (since the area of the lens is much greater than that of the pinhole), and, as we have just seen in fig. 11, are collected at one *point* by the lens. The same thing happens with the rays from every other point, which are collected

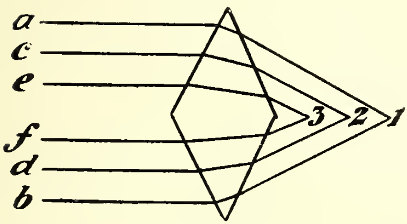

Fig. 10.

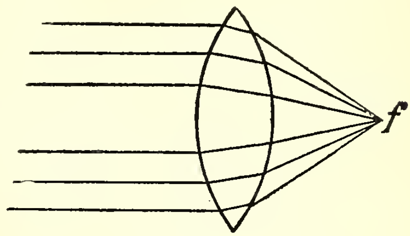

Fig. 11.

and brought to a spot on the ground glass, the position of which depends, of course, on the inclination of the original rays to the lens.

We said that the rays are collected at "points," but this is not exactly truc. In the pinhole image the fineness of definition depends on the size of the pinhole (see above). In the lens image it depends on a number of things which we now are to consider.

Let the reader always bear in mind that (in the above diagrams and those which follow) when rays are shown proceeding from a

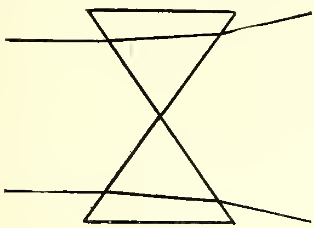

Fig. 12.

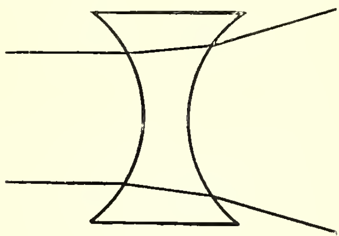

Fig. 13.

single point towards the lens, this point represents some one point in the object; and what is true of it is true of every other point in the same plane.

[3] *The Actual versus the Ideal Lens.*—We have now seen how an image (of a sort) is produced by a lens, but for the sake of simplicity we left a number of things out of consideration. These we must now pass to consider, for they are of great importance to the practical user of a lens. We will first get a clear idea of one or two terms in

common use, viz., focus, circle of confusion, focal length, and conjugate foci.

[4] *Focus.*—Among photographers the word focus is often wrongly applied. It is said of a lens that "its focus is six inches." Now a focus is not a lens; it is a place, the place where things are brought together. Thus in fig. 14, rays of light from a point fall upon the lens and are bent by it to meet at *f*; *f* is the "focus" of these rays. Another set of rays also parallel, but coming in a different direction, will meet at a point *f′*, which is the "focus" of *these* rays. For the sake of brevity we shall frequently use the word "focus" instead of "focal length" in these pages in cases where no ambiguity is thereby introduced. The ideal lens from the photographer's point of view bends all the sets of rays reaching it from every point, so that their meeting points (foci) all lie on a flat surface, or, in other words, the "focal plane," ss′, fig. 14, is really a plane

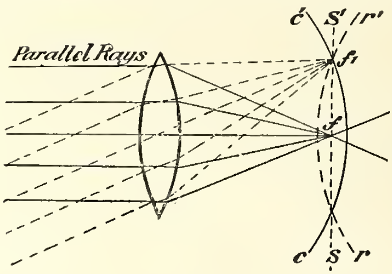

FIG. 14.

(flat) surface. But in practice this perfection is approached in varying degree. Some lenses have "focal planes" which are concave (cc′), and some "focal planes" which are convex (rr′) (fig. 14).

[5] *Circle of Confusion.*—We have spoken of the focus of a set of rays from a point as a point, and we must again say that it is really never a point but a tiny disc. You will see several reasons for this soon, but just here we can show you two prints which will help you to understand fig. 14. Suppose that the ground glass (ss′) is set back a little: you will see that the rays which met at *f* will cross and diverge, so that what at *f* are "points" (as near as we can get them) become discs which get larger and larger (as we set the screen further back) and so overlap, giving a confused or unsharp picture. Figs. 15 and 16 are taken with the same lens, the plate of fig. 15 being in the focal plane ss′, and that of fig. 16 being set back about a quarter of an inch. Owing to the fact that some points in the subject

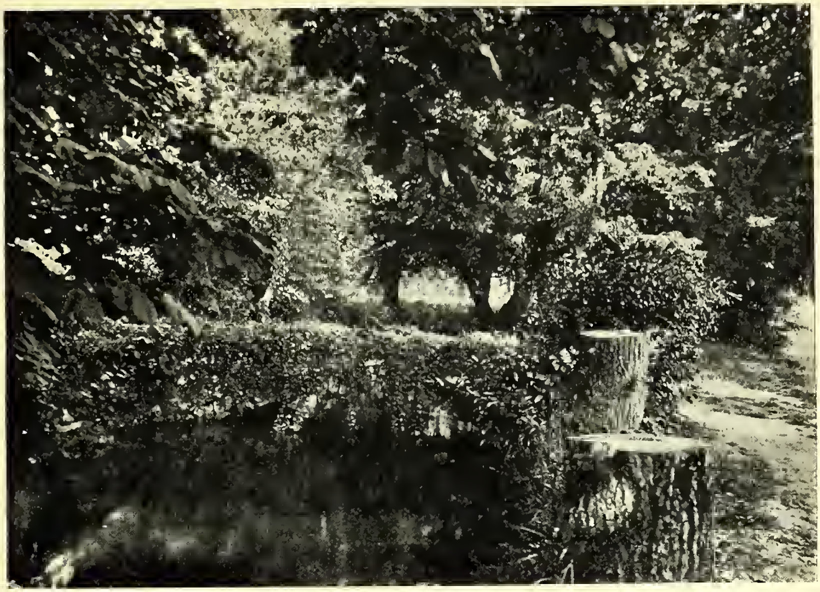

Fig. 15

Fig. 16.

Two views of the same landscape, taken from the same spot, the lower one showing exaggerated circles of confusion because the plate was not in the focal plane of the lens.

are so much brighter than their surroundings, the enlargements of the minute dots blot out the adjacent circles and appear as white discs. Compare these pictures with fig. 14 and you will get some idea of the way in which the action of the lens is there represented.

The overlapping of images shown in fig. 16 occurs to a certain extent in the most sharply focussed picture. Sharpness is merely a question of degree, and the amount of unsharpness tolerated in a picture depends upon the distance at which it is to be viewed, and therefore really upon its size; but it is a fact that a picture which is made up of circles ("circles of confusion") only $\frac{1}{100}$ of an inch in diameter appears quite sharp at a distance of ten inches (the normal distance at which a picture is viewed in the hand), so that this degree of sharpness ("circles of confusion" of $\frac{1}{100}$ inch diameter) has been taken as a kind of standard for the many purposes where such a standard is useful.

[6] *Focal Length* is more difficult to explain. It is the distance from the sharp image of an object a *very great way* off to the lens—or rather to a point before or behind the lens, the position of which we will talk about later (Chapter II.). It is mentioned here lest the reader should imagine that the text-book methods of measuring to the glass or to the stop are accurate. The object focussed must be so far away that the rays from any one point in it are practically parallel when they reach the lens. The reason for this is clear. Focal length is really a measure of bending power—rays are bent to meet at a point—and a lens can only do so much bending and no more. The further off an object is, the more nearly parallel the rays become. Theoretically they can never be parallel, but practically they do become so. The two lines down the side of this page appear parallel, but as a matter of fact they would meet at a point ten feet away, and the nearer the object the more divergent the rays and the more bending necessary to bring them to a focus. Hence in speaking of "focal length" we always mean for parallel rays, just as we should think it necessary to say, in regard to a cyclist's record, whether it was made on the road or the track.

1069. BOLAS, THOS. & GEORGE E. BROWN. The lens. A practical guide to the choice, use and testing of photographic objectives. London: The Photogram Ltd., 1902

First edition. "The aim of this book is twofold - to explain the properties of the photographic lens without the aid of mathematical formulae, and to give instruction in the selection and proper use of a lens."

8vo, orig. cloth. 176+16 pp. with 152 illus.

[7] *Conjugate Foci.*—As just mentioned, the bending power of a lens is fixed and limited (except as modified by the stop; see later), so that divergent rays reaching it are brought to a focus at a greater distance behind it than are parallel rays (compare figs. 14 and 17). For every distance (y) of the object from the lens there

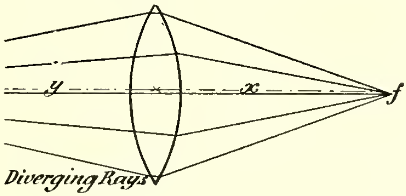

FIG. 17.

is a certain distance (x) of the lens from the plate. These two distances (x and y) depend upon each other (*i.e.* are "conjugate") until the object is taken so far away that the rays from it are practically parallel when they reach the lens. This is the position sometimes spoken of as "at an infinite distance from the lens." These conjugate foci (x and y) are of great importance in copying and enlarging. (See Chapter XV.)

CHAPTER II.

FOCAL LENGTH. "BACK FOCUS." CONJUGATE FOCI.

[1] *Focal Length.*—In [6], Chapter I., we spoke of focal length as a measure of the bending or refracting power of a lens—the shorter the focal length the more "powerful" the lens, because it bends the rays more strongly. We said that the focal length was the distance of the sharp image (of an object a great way off) not necessarily from the lens but possibly from some point before or behind it. We may now explain this statement. We shall thus learn the meaning of the terms "equivalent focal length" and "back focal length" (or "back focus").

If we take a lens of a certain kind, say one combination of almost any anastigmat, and focus on an object a great way off, we shall get, of course, a sharp image on the ground glass. Let the reader try this experiment himself, and measure—(1) The size of the image on the ground glass, and (2) the distance of the nearest surface of the lens from the plate. Now let him turn the lens the other way round, so that the previous face is turned towards the plate, and again focus. He will find this time that the image is the same size, but that the lens is now much nearer the plate—about an inch nearer in the case of the back combination of a $6\frac{1}{2}$-inch lens. This difference, which is often very puzzling to beginners, arises from certain well known lens laws which are not difficult to explain. The above is an instance of a lens having different "equivalent" and "back" focal lengths.

To understand how this point (or points—for there are two of them) comes about, let us begin with the refraction of light.

[2] *Refraction by Glass Plate.*—When a ray of light passes into a flat glass plate at an angle, *i.e.* not perpendicularly to the surface, it is bent when it enters the denser glass, and again to the same extent in the opposite direction, when it passes again into the air. The result is that it pursues a new path which is parallel to its original direction.

Thus in fig. 18 the ray A B is bent at B and again at C, the ray C D being parallel to A B, and appearing as though it had started from A′. Now if the glass plate be extremely thin, this shifting of the ray parallel to itself is so slight that the two paths appear to form one continuous line (fig. 19). When the glass is infinitely thin (*i.e.* has

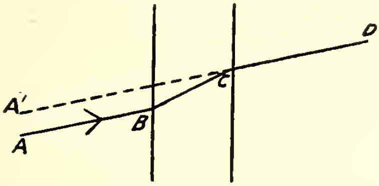

Fig. 18.

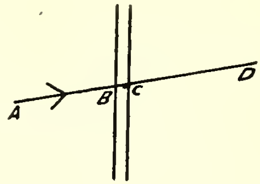

Fig. 19.

no thickness at all) they do form one straight line. A plate of no thickness is of course impossible, but the idea is convenient. Now let us apply a similar process to a lens.

[3] *Refraction by thick and thin Lens.*—When a ray of light falls upon a lens in a direction other than along the axis it is likewise bent

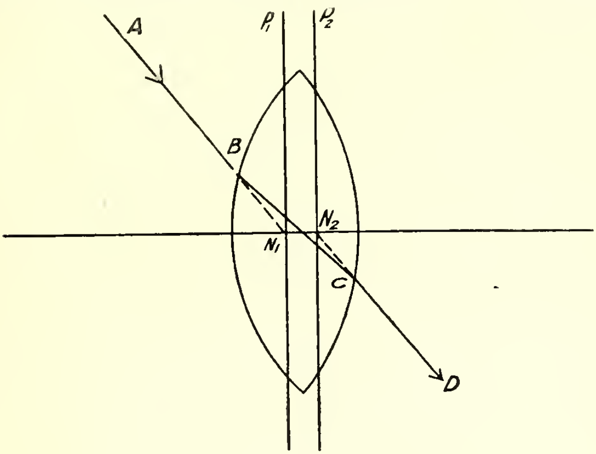

Fig. 20.

twice—once on passing into the glass and again on emerging into the air. Thus in fig. 20, A B is bent towards C, and goes on in the direction C D, parallel to A B. Now if we draw A B until it meets the axis of the lens in N_1 and C D, backwards, until it also meets the axis in N_2, we get two points which have interesting properties connected with the question of focal length. Notice first, however,

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that when the lens is infinitely thin this shifting of a ray passing through the centre does not take place (see fig. 21). Although there is no such thing as an infinitely thin lens any more than an infinitely thin plate, yet spectacle lenses of great focal length approximate to the condition of things diagrammatised in fig. 21. In such lenses the two points, N_1 and N_2, have come together.

[4] *Nodal Points.*—These two points, N_1 and N_2, are called the "nodal" or "Gauss" points of the lens, and the action of every lens more or less perfectly takes place as though it possessed these points with properties such as are shown in fig. 20, and which may be

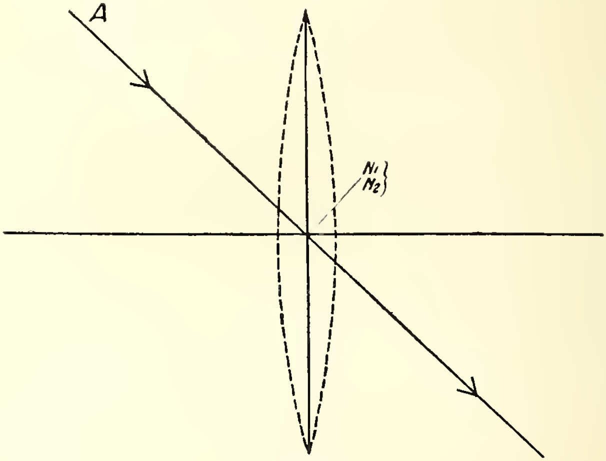


FIG. 21.

expressed thus. Any ray of light proceeding in any direction towards one of these points passes out of the lens as though it had passed through the other. For example, let us suppose we want to map out the continuation of the ray, A B. If we know the position of the nodal point N_2 (see Chapter XVII.), we have only to draw a line through N_2 parallel to A B to obtain the new path of A B: we need know nothing of the path of A B in the glass.

[5] *Nodal Planes.*—In fig. 22, lines are drawn through N_1 and N_2. These represent flat surfaces—nodal planes—passing through the nodal points at right angles to the axis of the lens. Just as the two points, N_1 and N_2, enable us to simplify the tracing of a ray of light passing through the centre of the lens (or to keep to the phraseology we are now introducing—through one of the nodal points), so these

nodal planes, P_1 and P_2, enable us to deal with those rays which are deflected by the lens, but, unlike rays passing through the first nodal point, do not emerge parallel, but pursue a path at an angle to that previously traversed. Thus, fig. 22 shows three rays proceeding from a point A and forming an image *a*. If we know the relative positions of object and image we can fix the directions of any number of rays going from A to *a*, by drawing lines from A on to P_1, dropping perpendiculars from these points, P_1, P_2, on to P_2, and joining this second series of points to *a*.

[6] *Nodal Points and Focal Length.*—Now we can come back to focal length. We have seen that these two planes with their nodal

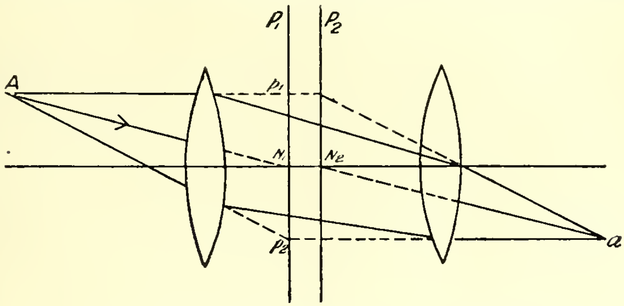


FIG. 22.

points, N_1 and N_2, form as it were a kind of halting-place in the optical system.

This is a purely and entirely imaginary conception: the rays of light between the two lenses in fig. 22 do not follow the course shown in the dotted lines, but the image is formed *as if they did.* That is a point we would like to emphasise, because it is so easy to come to think that the terms and diagrams of the nodal theory represent actual things. The node nearest the object is called the "node of admission," that nearest the image the "node of emergence." It is from this latter point that focal length is measured. The distance between this node of emergence and the image of an object an immense way off is the real (or equivalent) focal length of the lens. An infinitely thin lens placed at the node of emission would produce the same sized image. Hence the term "equivalent focal length," which is used to express this fact. Any combination of lenses can be said to have an equivalent focal length in this sense—*i.e.* an infinitely single lens placed in the node of emission would give an image identical with that of the combination. For two lenses,

however, to be exactly "equivalent" their focal lengths must be the same and their nodal points similarly situated: otherwise they will not act alike under all circumstances.

It is interesting to know whereabout these points are situated whenever we are concerned with the reproduction of objects of a certain size, as in exact copying or enlarging. If we are only occupied with the extension of camera required with any given lens, then

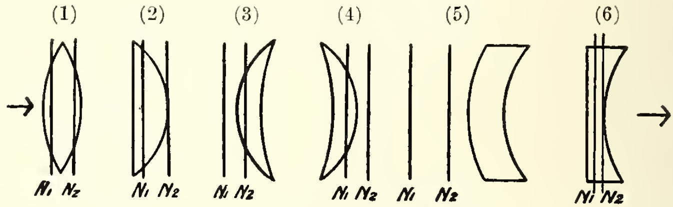


FIG. 23.—(1) Bi-convex; (2) Plano-convex; (3) Meniscus, convex side towards the light; (4) Meniscus, concave side towards the light; (5) Meniscus with surfaces of equal curvature; (6) Plano-concave.

"back focal length"—*i.e.* the distance of a sharp image of an infinitely distant object from the nearest surface of the lens—is what we want.

[7] *The Positions of the Nodal Points* are very various. They may be separated or may coincide, or may be crossed—*i.e.* the node of admission is nearer the plate than the node of emergence. Fig. 23 shows the position of the nodes in some ordinary types of lenses.

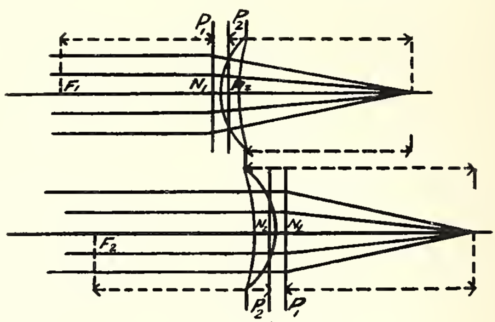


FIG. 24.

Fig. 24 shows the position of the nodal points in a compound meniscus as largely used for landscape work. When the lens is reversed, the real focal length remains the same, but the back focal length is appreciably greater. We reproduce this and the three

following diagrams from T. R. Dallmeyer's lecture on Focimetry (Traill-Taylor Memorial Lecture, 1898). Fig. 25 shows the position of the nodes in a whole plate rapid rectilinear of 11 ins. real focal length. They just cross one another, so that, although a symmetrical combination, its absolute focal length is slightly shorter than would

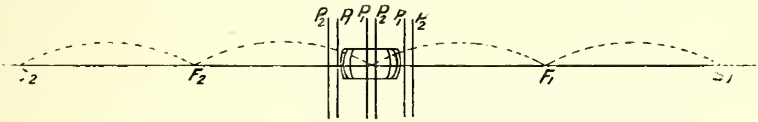


Fig. 25.

be expected from the measurement from the diaphragm to the image of an infinitely distant object.

Fig. 26 shows the disposition of the principal points in a Stigmatic of 6·4 ins. focal length. The points of the front combination (*a*) are near together, slightly crossed, and about $\frac{6}{10}$ths of an inch in front. In the case of the back combination they are not crossed, are near together, and as much as $1\frac{1}{4}$ ins. behind the lens. For the entire combination they are very close indeed to one another but only $\frac{3}{10}$ths of an inch from the shoulder of the back combination. So

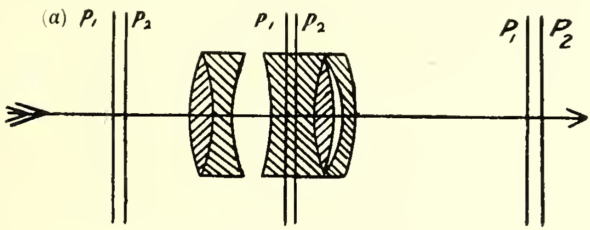


Fig. 26.

that the camera extension in using this lens as a combination would be noticeably longer than that for a symmetrical lens of the same absolute focal length, but in using either combination as a single lens with the diaphragm in front, the front combination would measure $\frac{6}{10}$ths of an inch, and the back $1\frac{1}{4}$ ins., longer in back focal length than the absolute focal length in each instance.

[The above applies to the stigmatic as first put on the market. At the present time the disposition of the nodal points is not as here shown.]

[8] *Nodal Points of Negative plus Positive Combination.*—Fig. 27 represents a combination of a positive lens of $9\frac{1}{2}$ ins. focal length and a negative lens of 13 ins. focal length separated by a distance of

4 ins. Its absolute focal length is $16\frac{1}{2}$ ins., and its back focal length $9\frac{1}{2}$ ins. Both the principal points and planes, N_1, N_2, are in front of the positive lens. The back focal length in the case of light incident upon the positive lens is $9\frac{1}{2}$ ins., but when the rays are incident upon the negative lens the back focal length is 22 ins. In the first case the absolute focal length is determined by the distance between the principal plane N_1 (in front of the lens) and the focal plane behind the lens, so that the back focal length is here shorter than the absolute focal length. In the second case the

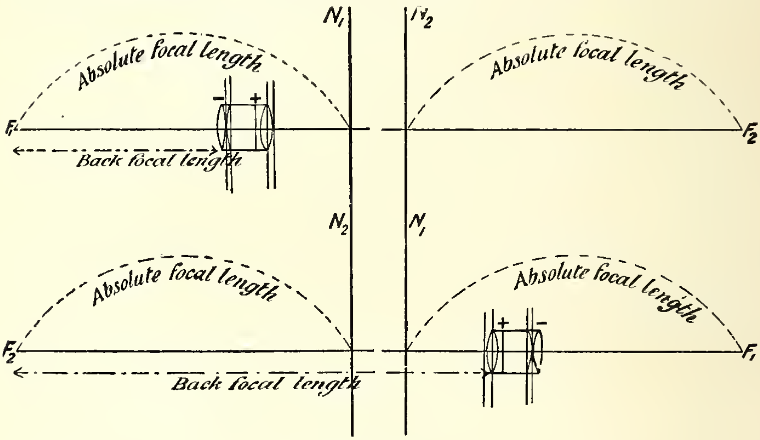


Fig. 27.

absolute focal length is the distance between the principal plane, N_2 (behind the lens), and the focal plane in the same direction, so that the back focal length in this case is considerably longer than the absolute focal length of the combination. (See also the Telephoto Lens, Chapter X.)

[9] *Focal Planes. Symmetric Planes.*—As we have seen, we know all about a lens, as regards its reproducing objects to scale, when we know its focal length and the position of its nodal points. Thus we may make a map of the lens as in fig. 28. P_1 and P_2 are the nodes of admission and emergence for the ray going from left to right: *vice versâ* for that shown dotted going from right to left. Parallel rays coming from a point at an infinite distance to the right or left come to a focus at one or other of the "focal planes" F, the distance from these planes to the nearest nodal plane being the real focal length of the lens. The planes, S_1 S_2, situate a distance from the nodal planes equal to twice the focal length are called (by Professor Silvanus P.

Thompson) "Symmetric planes." They possess this property, that an object placed in one has its image reproduced the same size in the other—*i.e.* to copy the same size the picture must be placed twice the focal length of the lens from the node of admission and the plate the same distance behind the node of emergence. The diagram shows that the old rule for finding the focal length of a lens—*i.e.* copy same

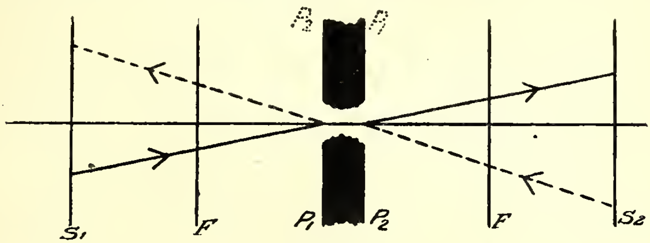


FIG. 28.

size and divide distance between plate and picture by 4—is not quite correct; it leaves out the nodal space (black in fig.), which must be subtracted from the distance between S_1 and S_2. On the other hand, in the case of a lens with crossed nodal points (fig. 29), the distance between the nodal planes must be added to the distance between S_1 and S_2.

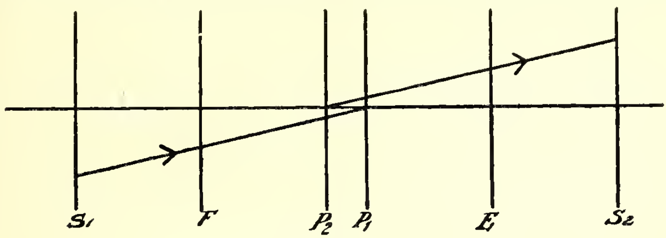


FIG. 29.

[10] *The Practical Importance of the Nodal Points* lies in this—that we can map out, as it were, any lens by a series of lines marking the position of the nodal points and the focal plane. For example, when we come to alter the focal length of a lens by combining it with a positive or negative lens (Chapter IX.) we can fix with certainty the relative positions of the glasses. To direct that a supplementary lens be placed one inch in front of a rectilinear conveys no exact meaning; but to direct that the node of admission of the rectilinear is to be, say, half an inch from the node of emission of the supplementary lens is a precise expression which, with the

knowledge of how to find nodal points given in Chapter XVII., enables us to combine lenses with greater accuracy. In telephoto calculations this is especially important; for ordinary purposes the rough and ready methods of trial and error are near enough for all practical requirements.

[11] *Conjugate Foci.*—As explained in [6] and [7], Chapter I., divergent rays come to a focus further away from the lens than do parallel rays. For practical purposes any ray of light which comes to a lens from a point at least fifty times the focal length of the lens is as good as parallel, and that point may be said to be infinity so far as this lens is concerned. But as soon as we step past this infinity point towards the lens we begin to find that the image is not sharp and that we must slightly increase the distance between the lens and the plate (getting thereby a larger image on the plate), and we must go on increasing this distance as the object we are focussing approaches the camera, for the reasons already set forth.

[12] *Rule for Conjugate Foci.*—Now for every position of the object there is a certain position of the camera, and these two distances, the distance of the object from the lens and of the lens from the plate, are called *conjugate foci.*

A very simple mathematical rule connects the distance from lens to object (D), the distance from lens to plate (d) and the enlargement or reduction of the object (*i.e.* the number of times a given *line* in the object is larger or smaller in the image). Note the word *line*, because some prefer to calculate reduction and enlargement on the basis of *area*, which introduces different conditions.

Let F be the focal length of the lens and r the ratios of enlargement or reduction.

Then the distance d is equal to F *plus* F divided by r. Expressed more shortly:

$$d = \mathrm{F} + \frac{\mathrm{F}}{r}.$$

On the other hand, D equals F *plus* F multiplied by r, or

$$\mathrm{D} = \mathrm{F} + \mathrm{F} \times r.$$

An example will show how simple this rule is. Suppose one wants to reduce a picture so that a 12-inch line becomes 3 ins.—*i.e.* $r = 4$. If a 6-inch lens is being used, d (camera extension) $= 6 + \frac{6}{4} = 6 + 1\frac{1}{2} = 7\frac{1}{2}$ inches, and $\mathrm{D} = 6 + 6 \times 4 = 6 + 24 = 30$ inches.

Bear two other things in mind which will help to use this for-

mula :—(1) Positions of image and object are reversible. If we were enlarging 3 ins. to 12 with a 6-inch lens we should place the lens and negative $7\frac{1}{2}$ ins. apart and the lens and paper 30 ins. apart. (2) The smaller conjugate is just r times the larger, *e.g.* $7\frac{1}{2} \times 4 = 30$. This is always the case, and is useful as a check on calculation.

[13] *Table for Conjugate Foci.*—To save calculation it is useful to work out this rule in tabular form. We give one way in which this is done.

Table of Enlargement and Reduction (from *The British Journal Photographic Almanac*).

Focus of Lens.	Times of enlargement and reduction (linear).							
	1.	2.	3.	4.	5.	6.	7.	8.
Inches. 2	Inches. 4 4	Inches. 6 3	Inches. 8 $2\frac{2}{3}$	Inches. 10 $2\frac{1}{2}$	Inches. 12 $2\frac{2}{5}$	Inches. 14 $2\frac{1}{3}$	Inches. 16 $2\frac{2}{7}$	Inches. 18 $2\frac{1}{4}$
$2\frac{1}{2}$	5 5	$7\frac{1}{2}$ $3\frac{3}{4}$	10 $3\frac{1}{3}$	$12\frac{1}{2}$ $3\frac{1}{8}$	15 3	$17\frac{1}{2}$ $2\frac{11}{12}$	20 $2\frac{6}{7}$	$22\frac{1}{2}$ $2\frac{13}{16}$
3	6 6	9 $4\frac{1}{2}$	12 4	15 $3\frac{3}{4}$	18 $3\frac{3}{5}$	21 $3\frac{1}{2}$	24 $3\frac{3}{7}$	27 $3\frac{3}{8}$
$3\frac{1}{2}$	7 7	$10\frac{1}{2}$ $5\frac{1}{4}$	14 $4\frac{2}{3}$	$17\frac{1}{2}$ $4\frac{3}{8}$	21 $4\frac{1}{5}$	$24\frac{1}{2}$ $4\frac{1}{12}$	28 4	$31\frac{1}{2}$ $3\frac{15}{16}$
4	8 8	12 6	16 $5\frac{1}{3}$	20 5	24 $4\frac{4}{5}$	28 $4\frac{2}{3}$	32 $4\frac{4}{7}$	36 $4\frac{1}{2}$
$4\frac{1}{2}$	9 9	$13\frac{1}{2}$ $6\frac{3}{4}$	18 6	$22\frac{1}{2}$ $5\frac{5}{8}$	27 $5\frac{2}{5}$	$31\frac{1}{2}$ $5\frac{1}{4}$	36 $5\frac{1}{7}$	$40\frac{1}{2}$ $5\frac{1}{16}$
5	10 10	15 $7\frac{1}{2}$	20 $6\frac{2}{3}$	25 $6\frac{1}{4}$	30 6	35 $5\frac{5}{6}$	40 $5\frac{5}{7}$	45 $5\frac{5}{8}$
$5\frac{1}{2}$	11 11	$16\frac{1}{2}$ $8\frac{1}{4}$	22 $7\frac{1}{3}$	$27\frac{1}{2}$ $6\frac{7}{8}$	33 $6\frac{3}{5}$	$38\frac{1}{2}$ $6\frac{5}{12}$	44 $6\frac{2}{7}$	$49\frac{1}{2}$ $6\frac{3}{16}$
6	12 12	18 9	24 8	30 $7\frac{1}{2}$	36 $7\frac{1}{5}$	42 7	48 $6\frac{6}{7}$	54 $6\frac{3}{4}$
7	14 14	21 $10\frac{1}{2}$	28 $9\frac{1}{3}$	35 $8\frac{3}{4}$	42 $8\frac{2}{5}$	49 $8\frac{1}{6}$	56 8	63 $7\frac{7}{8}$
8	16 16	24 12	32 $10\frac{2}{3}$	40 10	48 $9\frac{3}{5}$	56 $9\frac{1}{3}$	64 $9\frac{1}{7}$	72 9
9	18 18	27 $13\frac{1}{2}$	36 12	45 $11\frac{1}{4}$	54 $10\frac{4}{5}$	63 $10\frac{1}{2}$	72 $10\frac{2}{7}$	81 $10\frac{1}{8}$

The object of this table is to enable any manipulator who is about to enlarge (or reduce) a copy any given number of times, to do so without troublesome calculation. It is assumed that the photographer knows exactly what the focal length of his lens is, and that he is able to measure accurately from its nodal points. The use of the table will be seen from the following illustration :—A photographer has a *carte* to enlarge to four times its size, and the lens he intends employing is one of 6 ins. equivalent focus. He must, therefore, look for 4 on the upper horizontal line, and for 6 in the first vertical column, and carry his eye to where these two join, which will be at 30—7½. The greater of these is the distance the sensitive plate must be from the centre of the lens; and the lesser, the distance of the picture to be copied. To *reduce* a picture any given number of times the same method must be followed, but in this case the greater number will represent the distance between the lens and the picture to be copied ; the latter, that between the lens and the sensitive plate. This explanation will be sufficient for every case of enlargement or reduction.

If the focus of the lens be 12 ins., as this number is not in the column of focal lengths, look out for 6 in this column and multiply by 2, and so on with any other numbers.

For most purposes it is accurate enough to measure the distances from the stop of rectilinear lenses or from near the centre of single lenses, but in cases where it is desired to scale off an enlarging camera so that focussing is not required, this is not sufficiently exact. The correct points from which to measure the two distances are the nodal points of the lens. See [4] above.

[14] *Conjugate Formula.*—It is well to remember also that the letters P and Q are generally used in works on optics to denote conjugate foci, and the letters v and u the respective distances of the foci from the lens. The formula connecting these two conjugate focal lengths (u and v) with the focal length for parallel rays F, is $\frac{1}{u}+\frac{1}{v}=\frac{1}{F}$, which becomes more applicable by those unused to algebra if we express it thus :—

$$F\,(v+u)=u\,v\,;$$

or in other words the conjugate focal lengths added together and multiplied by the equivalent focal length are equal to the result of multiplying one conjugate by the other.

Thus from the table :—

$$6\,(18+9)=18\times 9$$

CHAPTER III.

ANGLE OF VIEW. INEQUALITY OF ILLUMINATION.

[1] *Angle of View.*—There is some confusion as to the exact definition of "angle of view." In fig. 30 we have a plate (shown in solid lines), supposed to be bearing an image formed by the lens, L. According to the usual convention the angle included between the lines drawn from the opposite ends of the plate to the lens (or

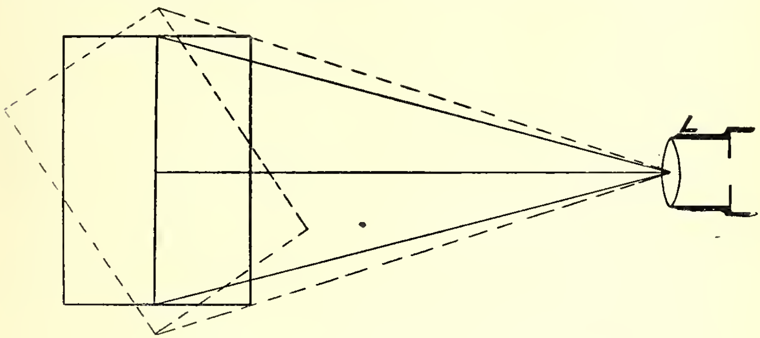


FIG. 30.

to the nodal point of emergence) is the "angle of view." It is, however, insisted that a more scientific definition is to specify the angle included between the lines drawn from opposite ends of the diameter of the circular field of the lens—*i.e.* from the diagonal of the plate. The difference is shown by the dotted portion of the figure in which the plate is supposed to have been rotated so that its diagonal is vertical. Whichever standard is adopted the table on next page can be used for calculating the angle of view.

Example.—Given a lens of 13 ins. equivalent focal length. Required the angle included by it on plate $3\frac{1}{4} \times 4\frac{1}{4}$, on "base" basis.

Dividing $4\frac{1}{4}$ by 13 we have as quotient ·327—midway between ·317 and ·335 in our table. Therefore angle is 18° 30′.

On diagonal basis $5·3 \div 13 = ·408$, corresponding to 23°.

TABLE OF VIEW-ANGLES. By CLARENCE E. WOODMAN, Ph.D.

Divide the Base * of the Plate by the Equivalent Focal Length of the Lens.

If the quotient is	The angle is	If the quotient is	The angle is	If the quotient is	The angle is
	Degrees.		Degrees.		Degrees.
·282	16	·748	41	1·3	66
·3	17	·768	42	1·32	67
·317	18	·788	43	1·36	68
·335	19	·808	44	1·375	69
·353	20	·828	45	1·4	70
·37	21	·849	46	1·427	71
·389	22	·87	47	1·45	72
·407	23	·89	48	1·48	73
·425	24	·911	49	1·5	74
·443	25	·933	50	1·53	75
·462	26	·954	51	1·56	76
·48	27	·975	52	1·59	77
·5	28	1·	53	1·62	78
·517	29	1·02	54	1·649	79
·536	30	1·041	55	1·678	80
·555	31	1·063	56	1·7	81
·573	32	1·086	57	1·739	82
·592	33	1·108	58	1·769	83
·611	34	1·132	59	1·8	84
·631	35	1·155	60	1·833	85
·65	36	1·178	61	1·865	86
·67	37	1·2	62	1·898	87
·689	38	1·225	63	1·931	88
·708	39	1·25	64	1·965	89
·728	40	1·274	65	2·	90

* Or diagonal. The diagonals of ordinary plates are as follows :—

$3\frac{1}{4} \times 3\frac{1}{4}$ diagonal	4·6 ins.	$5 \times 7\frac{1}{2}$ diagonal	9·0 ins.
$3\frac{1}{4} \times 4\frac{1}{4}$,,	5·3 ,,	$6\frac{1}{2} \times 8\frac{1}{2}$,,	10·7 ,,
4×5 ,,	6·4 ,,	10×8 ,,	12·4 ,,
$4\frac{3}{4} \times 6\frac{1}{2}$,,	8·0 ,,	12×10 ,,	15·6 ,,
7×5 ,,	8·6 ,,	15×12 ,,	19·4 ,,

[2] *Narrow angle, Medium angle, and Wide angle Lenses.*—We have seen that the greater the focal length of the lens compared with the length of the plate the narrower the angle, and if lenses were made to cover plates of a certain size neither more nor less we could exactly classify lenses according to this proportion. But as any lens which will cover a large plate will cover a small one—the greater includes the less—and as many lenses when stopped down

will cover a much larger plate than when at full aperture, there is only one way in which we can call lenses wide or narrow angle. There are lenses which will only cover a plate at a certain narrow angle: stopping down does not extend their fields. They are rightly called narrow angle lenses. There are similarly lenses which *will* work at a very wide angle, covering a plate from corner to corner at an angle of 90° and more. All lenses will not do this, and therefore those that will are rightly called wide angle lenses. But here lies the curious error into which many beginners fall.

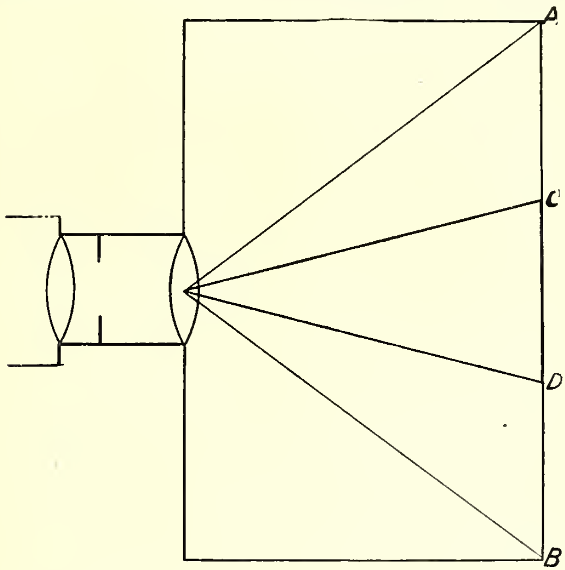


Fig. 31.

They seem to suppose that wideness of angle is an inherent property of the lens. A moment's consideration will show that by offering a smaller plate to the lens the result is exactly the same as though a "narrow angle" lens were used. Suppose we had a lens (fig. 31) covering at an extremely wide angle the plate A B, and suppose we substitute for A D a much smaller plate, C D. The angle of view is then only that shown on the heavy lines.

Angle of view has a certain effect on the picture (see Chapter XII.), and it does not matter one iota (except so far as concerns good definition) what lens is used—the drawing of the picture will be the same whether the lens appear in the maker's catalogue as narrow,

medium, wide angle. "Narrow angle" and "wide angle" are titles used by the optician to denote the maximum performance of the lenses, and while the narrow angle lens of the catalogue cannot usually act as a wide angle, the wide angle lens of the catalogue can always function as wide, medium or narrow angle according to the area of plate presented to it.

[3] *Inequality of Illumination* is the defect noticed especially with lenses used over a wide angle whereby the parts of the plate near the edges are not so well lighted as the central part. It arises from two sets of causes, one inseparable from the lens and the other due to defective mounting. We will take the latter first. Fig. 32 shows two ways in which this may take place. The bundle of rays of which A B is the chief or central ray passes right through the lens system, but in the case of C D, which falls more slantwise, the outside part of the pencil is cut off by the lens mount, whilst the inside part of the pencil, though passing through the first lens, falls on the interior surface of the mount. The diagram makes clear also how inequality of illumination from this cause is improved by a small stop. Imagine the central aperture reduced: it will then be seen that oblique rays pass through the lens system almost as readily as those more nearly parallel to the axis.

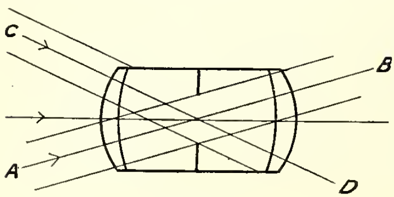


FIG. 32.

Inequality of illumination arising from this cause is, of course, quite irregular; it depends on the mounting of the lens. In speaking of it it is usual to distinguish between the angle over which the lens can cover without the mounting interfering and the angle at which the mounting is interfering as much as is possible. The next paragraph will explain the practical importance of these angles.

[4] "Angle of cone outside of which aperture begins to be eclipsed," "Angle of cone of illumination," are terms denoting, in the first case, the angle over which reasonably even illumination is given; and in the second, the total angle over which the lens gives definition and illumination of a sort. See [16], Chapter XVII.

[5] *Unavoidable Inequality of Illumination.*—The other set of causes of inequality of illumination arises from natural laws and cannot be eliminated from the most perfect lens, except by added optical devices. Of these causes the two most important are :—

(1) The diaphragm aperture acts as though it were contracted in area when admitting oblique rays, becoming narrowed down just as a penny held at arm's length between the thumb and finger and slowly twisted round gradually passes from a disc into a rod.

(2) The distance from diaphragm to plate is greater for oblique rays than for parallel rays, and hence the light is diminished according to the square of this distance.

The loss of illumination due to these disturbing causes can be calculated, and the following figures give the illumination for rays making different angles with the axis, the illumination for rays parallel with the axis being taken as 100. (Miethe.)

Angle of Ray to Axis of Lens.	Illumination of Field.	Angle of Ray to Axis of Lens.	Illumination of Field.
0°	100	30	56
5	98	35	45
10	94	40	34
15	87	45	25
20	78	50	17
25	67	55	11

A more practical form of expressing similar results is as follows, in which the figures are W. K. Burton's.

The illumination at the centre of a 12×10 plate being taken as 1 in each case, the illumination at the edge of the plate falls off with various lenses in the following manner:—

24 ins. focal length, - - - - - -	$\frac{3}{4}$
16 ,, ,, ,, - - - - -	$\frac{1}{2}$
12 ,, ,, ,, - - - - -	$\frac{1}{3}$
Angle of 100° - - - - -	$\frac{1}{6}$

These figures represent a more rapid falling off than is indicated by the table above, which is drawn up on theoretical grounds and represents the ideal lens. The important point about both of them is that photographers do not generally discover the great differences which may strike the casual reader as here indicated. A more careful examination of the table will show that the illumination falls off slowly at first and more rapidly afterwards. At an angle even of 60°, which is that corresponding to a lens of about $7\frac{1}{2}$ ins. focal length on a whole plate, the illumination falls off gradually to rather more than half at the extreme edges of the plates. Considering the latitude of plates and the different illumination of

different parts of the subject photographed, it is not surprising that this disparity should go unnoticed. At the same time, these figures show the best illumination possible with any lens, and as Burton's results show, ordinary lenses under practical tests do not come up to them entirely. On the other hand, when very wide angle lenses are used, the loss at the edges of the plate is much greater than it has ever been possible to ignore, and various auxiliary appliances have been devised to remedy it.

[6] *Equalising Illumination.*—In order to get rid of this inequality of illumination, several devices have been proposed. The star diaphragm of Meydenbauer (see fig. 33), is made to replace the ordinary diaphragm. The principle of it is evidently to cut out the axial rays more than the marginal rays.

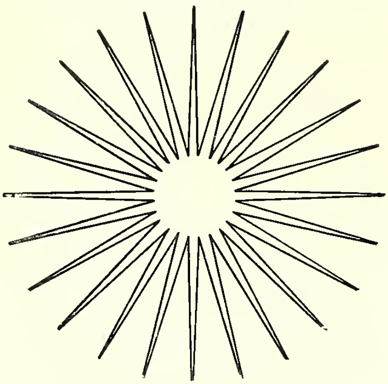


Fig. 33.

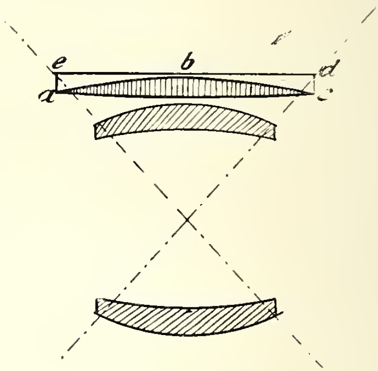


Fig. 34.

Dr. Adolf Miethe's compensator acts in a different way. It consists of a thin plano convex lens (*a b c*, fig. 34) of obscured glass cemented to a thin plano convex lens (*e b d*) of white glass. The two glasses having the same curvatures and optical constants, their combination acts like a flat glass plate. The compound lens is placed in front of the objective as shown in the figure, and when the curvature and blackness of the obscured glass are correctly adjusted, the central and marginal portions of the field are found to be brought to the same illumination.

De la Crouée's mechanical device of a revolving sector on the lens hood secures exact equality of illumination when used with a comparatively small stop. The arrangement is more akin to a shutter, and the reader is referred to the paper on the subject by T. R. Dallmeyer (*The Photographic Journal*, March 29th, 1898).

CHAPTER IV.

THE DIAPHRAGM (OR STOP): ITS USE AND EFFECTS.

[1] *Diaphragm and Stop.* — In photography, diaphragm and stop are held to mean the same thing, although usually in optics the diaphragm is a plate with a hole in it which is the diaphragm aperture. In photographic lenses, the series of apertures are made in a rotating plate, when they are known as "rotating stops," or in separate plates which are slipped into the lens mount and are called Waterhouse diaphragms, after their inventor. Most usually, however, the diaphragm apertures are formed by a set of thin plates which open and close like the iris of the eye, hence "iris" diaphragms. The form in which the diaphragm is made does not affect its action on the lens.

[2] *The Diaphragm and the Lens.*—Practically every property of photographic lenses is more or less altered by the diaphragm; in most cases the action of the lens is improved. In one, however, the stopping down of the lens makes no difference—*i.e.* in the distortion given by a single lens. In general, the effect of the diaphragm is to cut down the rays passing through the lens, so that the cone of rays reaching the plate is (1) narrower, and (2) comes *mostly* through the centre of the lens. The second result cannot be completely realised when, as is most frequently the case, oblique or divergent rays are passing towards the lens. See fig. 36.

[3] *Stopping down.*—The most familiar example of the functions of the diaphragm is that which every purchaser of a camera finds out in a few hours, viz., that in order to get various planes equally into focus at the same time, the lens must be stopped down. This arises from the fact that no lens gives an image of geometrical points. The lens image is made up of circles, and these circles may vary in size in parts of the image within certain limits, and yet give a picture which is to all intents and purposes sharp all over. This power arises, not from the excellence of any lens or type of lens, but from

the varying inability of the human eye to distinguish critically sharp definition. It is thus impossible to treat these subjects of depth of

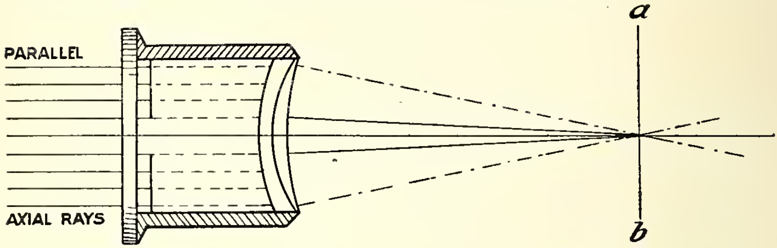


Fig. 35.—Showing the effect of "stopping down" on a pencil of rays coming through the centre of the lens.

focus and depth of field by any fixed rule, but Chapter V. gives the gist of the matter. Focussing several planes at one time is just a

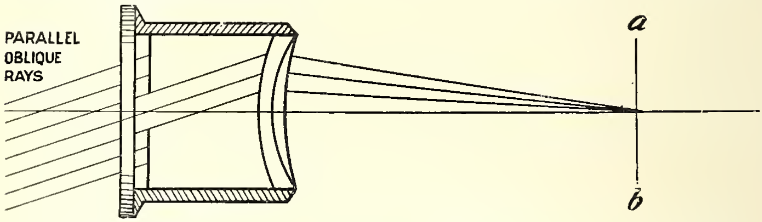


Fig. 36.—Showing effect of "stopping down" on oblique parallel rays; the pencil which passes is not confined to the centre of the lens.

matter of getting the pencil of rays which reaches the plate narrowed down. The images of objects which are nearer to the camera are

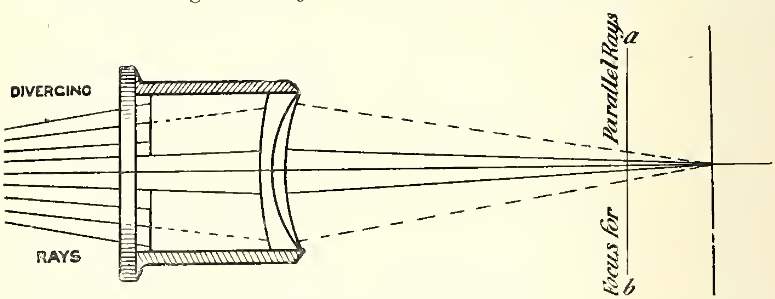


Fig. 37.—Showing how "stopping down" enables near and distant objects to be focussed simultaneously.

brought to a focus behind the focus for parallel rays (see [11], Chapter II.). If the pencil of rays in each case is narrow, it is

possible to get the images of objects both near and distant reasonably sharp in the same plane; whilst if the pencil were broad (and therefore more strongly converging), it would be impossible.

[4] *Small Stop and Aberration.*—The reader of Chapters VI. and VII. will see that a small diaphragm improves definition which is defective from whatever aberration.

In the case of chromatic aberration the narrowed pencil of rays restricts the foggy zones which are caused by uncombined rays.

Spherical aberration (see Chapter VI.) is improved or altogether removed by stopping down.

Curvature of field and astigmatism are likewise reduced when the lens is stopped down.

[5] *The Diaphragm and Exposure. Rapidity.*—The smaller the stop which is inserted in a lens the less the light admitted and therefore the longer exposure required. A photographer must know the relative exposure required for each of his set of stops, and therefore some system of marking them must be adopted. We might simply mark them with numbers representing the area or the diameter. If we do the latter we must recollect that the area of a circle is proportional to the square of the diameter (*i.e.* to the diameter multiplied by itself). If we had a series of holes 1 inch, $\frac{1}{2}$ and $\frac{1}{4}$ and $\frac{1}{8}$ inch in diameter, the areas would be in the proportion of 1, $\frac{1}{4}$, $\frac{1}{16}$ and $\frac{1}{64}$, thus:—

Holes (diameter) - - -	1	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$
Areas proportional to - - -	1	$\frac{1}{4}$	$\frac{1}{16}$	$\frac{1}{64}$

But if we mark only area or diameter on a stop it tells us nothing, because we are leaving out the question of the focal length of the lens; our numbers would be useful so far as that particular lens was concerned, but would not be comparable with any lens of a different focal length. This is because the light admitted by the diaphragm is diminished in intensity in proportion to the distance between stop and plate. This diminution takes place in proportion to the square of the distance. A stop placed in front of a lens of 8 ins. focal length gives an intensity of light four times that produced by substituting a lens of 16 ins. focal length: the same amount of light passes through the diaphragm in each case, but in the second case a picture twice the size (or four times the area) is produced.

We can combine these two facts—variation of exposure with (1) focal length of lens and (2) diameter of aperture—into one number. Most beginners find this a very difficult point to understand. There-

fore we may venture to express the facts a little loosely in order to familiarise the idea.

We have just seen that a lens of great focal length must have a larger aperture than one of less focal length in order to give the same intensity of light. That is quite true. However great a focal length a lens may have, we can get any given intensity simply by making the aperture big enough. Therefore it is easy to look upon the condition which determines the exposure we must give as the proportion the aperture bears to the lens.

The fewer times the diameter of the aperture will divide into the focal length of the lens, the less exposure; the more times, the longer the exposure. We may represent this condition thus:—

$$\text{Exposure is determined by } \frac{\text{Focal length}}{\text{Diameter of aperture}}.$$

Now this expression includes both focal length and aperture, and is therefore true for one lens as much as for another of quite different

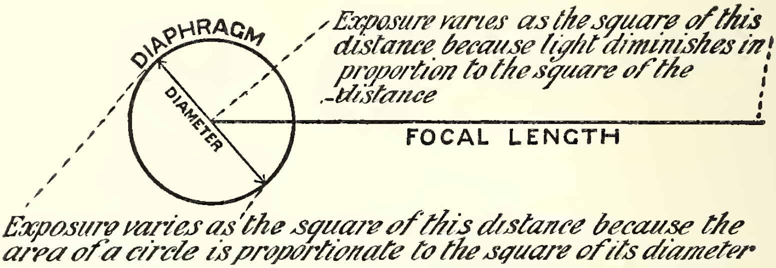


FIG. 38.—Diagrammatic rule of the relation of diaphragm-aperture and focal length to exposure.

focal length. Opticians have devised many modifications or elaborations of this method, but they are all identical in taking the ratio of focal length to aperture as their basis.

Although this ratio determines the exposure, the figure obtained by dividing the focal length of the lens by the diameter is not directly proportional to the exposure, because the exposure varies as the square of the focal length and inversely as the square of the diameter of the aperture. Both of these factors are included when we use the square of the ratio.

Exposure is proportional to—

$$\left(\frac{\text{Focal length}}{\text{Diameter of aperture}}\right)^2 \textit{ i.e. } \left(\frac{\text{Focal length} \times \text{focal length}}{\text{Aperture diam.} \times \text{aperture diam.}}\right)$$

The student who will work out the following example will have mastered the elements of the subject. Three lenses have focal lengths and apertures as follows:—12 ins. and $\frac{1}{2}$ inch; 6 ins. and $\frac{1}{4}$ inch; 8 ins. and $\frac{1}{3}$ inch. Show by applying the rules of (1) diminution of light and (2) relation of area of circle to diameter that all require the same exposure.

Answer.—(1) Exposures vary:

(1) As squares of focal lengths.

Therefore relative exposures are—

	12×12	6×6	8×8
i.e. as	144	36	64

(2) *Inversely:* as squares of diameter of stops.

Therefore relative exposures are—

4	16	9

Combining (1) with (2) we get—

	144×4	36×16	64×9
or	576	576	576

[6] *Focal Aperture.*—The more convenient way to make this calculation is according to the well known rule—Divide focal length by diameter of aperture; this gives us the "focal aperture" of the lens. The exposures are proportional to the squares of these focal apertures. A glance at the focal lengths and apertures shows us that the three lenses all work at what is called *f*24 (see later), but it is well to bear in mind the dissected example, because it brings into equal prominence what is often entirely ignored, viz., that exposure varies as the square of the focal length. Though this is of little importance in landscape work where the lens is usually used at its equivalent focal length, it cannot be neglected in copying or in other cases in which the camera is extended to get near objects into focus. In these cases the exposure must be increased in the proportion of the square of the increased focal length to the square of the original focal length. Thus if a lens of 10 ins. focal length is used so that its focal length is extended to 12 ins., the exposure must be increased in the proportion of $(12)^2 : (10)^2$—*i.e.* in the proportion of 144 to 100, *i.e.* about $1\frac{1}{2}$ times as much. If one is copying a diagram same size so that the camera is extended to double the focal length (see [13], "Conjugate Foci," Chapter II.), exposure must be four times. The student should bear these facts in mind and remember that the numbers with which a lens is marked wrongly indicate the working aperture whenever the lens is

used appreciably further from the plate than when it is defining objects at an infinite distance. It is therefore an advantage to know the actual diameters of the various apertures which, divided by the focal length actually employed, give the aperture ratios (f numbers) of the stops, which are correct under the special conditions; or the numbers (f16, etc.) on the lens mount can be multiplied by the extended focal length and divided by the equivalent focal length.

Having thus explained the two factors involved in expressing the aperture of the diaphragm and why it is necessary to square the ratio $\frac{f}{d}$ when calculating relative exposures, we can now pass to consider the various ways in which opticians mark their lenses.

[7] *F Numbers* (f8, f16, etc.) are fortunately the most general figures. They are simply the ratio $\frac{f}{d}$ which we have just explained. Thus to find the number of any stops, divide the focal length of the

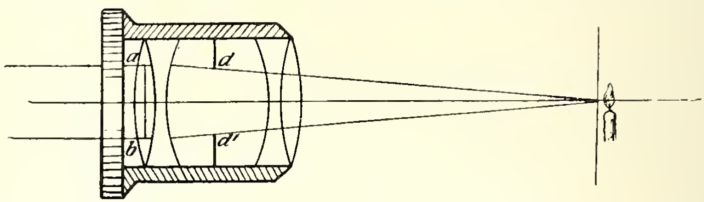


Fig. 39.

lens by the diameter of the aperture. This is accurate in the case of single lenses, but not when a converging lens is in front of the stops. In the former case the rays fall directly on to the aperture, and the area of the aperture is the total illuminating surface, but a converging lens concentrates the light which falls upon its front surface and sends on a cone of rays to the diaphragm. The sectional area of the diaphragm, d d', fig. 39, is a little less than the effective aperture of the lens, the diameter of which is a b. This point is of some considerable importance when lenses of large apertures are concerned. In order to get the real aperture several methods can be followed.

(1) Focus the camera on an infinitely distant object and replace the focussing screen by a piece of cardboard with a pinhole in the centre. This is conveniently carried in a dark slide, the two shutters being withdrawn. Bring into the dark room and place a lighted candle behind the hole. This being at the equivalent focus of the lens, the rays which reach the front surface of the front lens are

parallel and form a disc which is the true aperture of the diaphragm. The diameter of the disc can be measured with a pair of dividers, the glass being breathed upon to make the image visible; or a bit of ground glass may be placed against the lens hood: or a piece of bromide paper may be fitted in the lens cap, exposed to a little magnesium ribbon (burnt outside the pinhole), and afterwards developed.

[8] *In figuring with F numbers*, the system of marking lenses is simple and direct, but it has the disadvantage that the exposures are proportional to $\left(\frac{f}{d}\right)^2$ and not to $\frac{f}{d}$. Therefore opticians make it a custom to adjust the diameters of the stop so that each requires twice the exposure of the preceding one, the diameters being made proportional to the square roots of the numbers 1, 2, 4, 8, 16, 32, 64,—*i.e.* to 1·41, 2, 2·83, 4, 5·65, 8. The series of stops are thus as follows:—f3·16, f5·66, f8, f11·3, f16, f22·6, f32, f45, f64, and the only thing the beginner must bear in mind is that exposures are not proportional to the numbers. Thus f16 requires four times the exposure of f8, because 16×16 is four times 8×8; but remembering the rule that any stop requires double the exposure of the preceding and half that of the succeeding, it is difficult to go wrong.

[9] *Other Systems of marking Diaphragms.*—The Royal Photographic Society called an aperture of diameter one fourth the focal length (f4), No. 1; No. 2 is an aperture of twice the area—*i.e.* 1·4 times the diameter (*i.e.* 11·4); No. 4 has an aperture one eighth the focal length (f8), and so on, the numbers representing relative exposures. This is known as the U.S. (uniform system). This system is now (1902) as good as obsolete.

Many French lenses are marked according to the method of the Paris Congress of 1889. F10 is taken as the unit aperture, the series advancing in the same way as the U.S. Thus f14, which requires twice the exposure of f10, is 2; f20 is 4.

J. R. Dallmeyer introduced a system in which f3·16 (*i.e.* $f\sqrt{10}$) is the unit, the succeeding numbers being proportional to the exposures required. No. 2 is f4·47, No. 4 is f6·32, but Dallmeyer's lenses are now marked according to the f notation.

C. P. Goerz likewise makes f3·16 his unit, but marks his stops with figures which work out to different stops.

Voigtländer again chooses the f3·16 unit with still other actual apertures.

Carl Zeiss originally selected f100 as the unit, the lenses of larger aperture receiving the smaller numbers. No. 1 is thus f180; No. 2,

requiring half the exposure, *f*71, and so on; afterwards, however, *f*50 has been taken as the unit. Hence No. 7 is now *f*50, No. 2, *f*36, and so on.

[10] *Rapidity.*—The rapidity of a lens depends upon (1) and mainly, the aperture (*f* ratio) at which it works, (2) the thickness and color of the glass, and (3) the number of reflecting surfaces. No. 1 is most important, because it may vary within extremely wide limits, but nevertheless follows a certain simple rule; (2) and (3) are factors which do not lend themselves to calculation; moreover, they vary only to a slight extent in commercial lenses. At the same time it is not correct to suppose that the thickness and the color of the glass and the number of reflecting surfaces may therefore be entirely ignored. The generalisation that all lenses working at *f*16 are of the same rapidity is only approximately true, though doubtless true enough, in 999 cases out of a thousand. Still, careful workers know otherwise, and in their Actinograph Messrs. Hurter & Driffield include an auxiliary scale providing for single lenses, doublets and triplets, the loss of light from the several surfaces being considered appreciable by them. But for ordinary practical purposes an aperture of *f*16 will be as rapid whatever the lens, and it is only in maximum rapidity—the largest stop with which the lens will work satisfactorily—that lenses differ greatly. Portrait lenses which work at *f*3 or *f*4 are the most rapid: then follow the newest of the anastigmats, such as the Planár, with the aperture of *f*4·5; then other anastigmats working at *f*6, then rapid rectilinears (so called) of the days before Jena glass which work at *f*8; view lenses have a maximum rapidity of *f*12, and older wide angle lenses of *f*16.

Defects due to the Diaphragm.

[11] *Distortion.*—When a straight line is photographed with a single lens having a stop in front of it, it is bowed out as shown in fig. 42, if it falls near the edge of the plate. If the stop is behind, it is bowed inwards. If the line falls at the middle of the plate (fig. 43) there is no distortion. This defect, which is not of great account except when the lens is to be used for copying, is due to the fact that the passage of the rays through the diaphragm, whether it be in front of or behind the lens, has the effect of causing *the edges of the lens to form the edges of the picture, and the centre of the lens the centre of the picture.* This will be seen from the figures. R R R (figs. 40 and 41) are parallel rays coming from the edge of the objects. In both cases

(diaphragm in front of, and behind, the lens) only the edges of the lens come into use in forming the image from these rays: the diaphragm in fig. 40 shielding the centre of the lens, and in fig. 41 cutting out those rays which have passed through the centre. Now we know that the edges of a lens bend rays more than does the central part, and this fact explains why in fig. 40 we have the marginal parts of the image brought further in, thus producing the well known barrel distortion, and in fig. 41 thrown further away

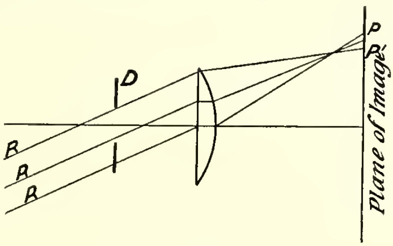


Fig. 40.

from the centre of the field, thus producing the so-called pincushion distortion. Loosely expressed, the condition shown in fig. 40 is as though we were using lenses of shorter and shorter focus as we pass from the centre of the plate to the edges, and in fig. 41 as though we were gradually increasing the focal length of the lens under the same circumstances. The diagrams show how it is that

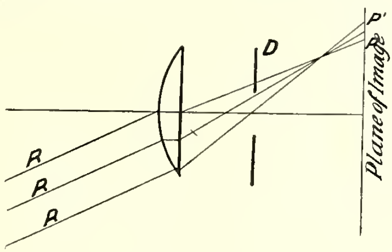


Fig. 41.

the distortion increases as the distance of the stop from the lens is increased.

The reader will judge from the figs. 42 and 43 that the effects of distortion are not very serious. For landscape and portrait work they are negligible; in architecture they may interfere; in copying, they are prohibitive.

The practical moral is that the disadvantage of single lenses, so far

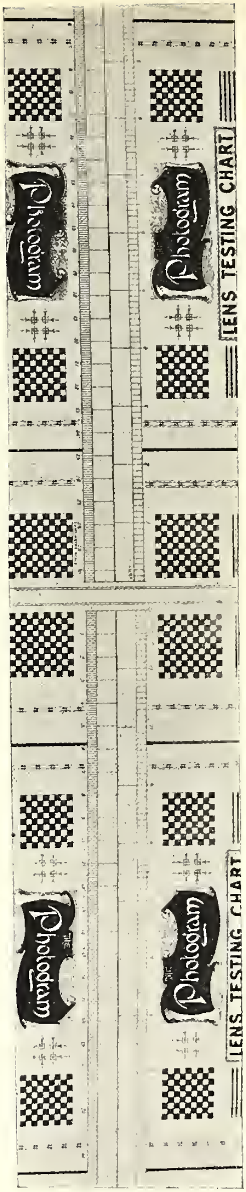


FIG. 42.

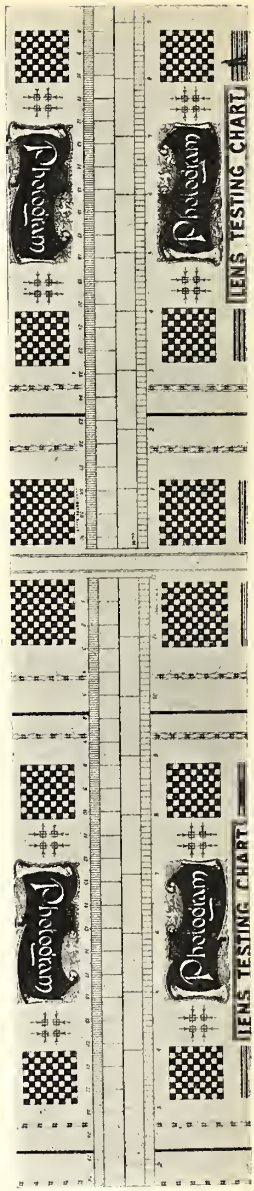


FIG. 43.

Curvilinear Distortion.—Note the curved form of central scale in fig. 42 : fig. 43 shows the scale straight. The difference is best seen by holding the page sideways.

as concerns distortion, is, to all intents and purposes, *nil*, unless one is reproducing plans and drawings, or photographing architecture with a single lens of fairly short focal length. With a single lens of greater focal length, used on a relatively small plate (*i.e.* when a com-

FIG. 44.

paratively narrow angle is included), the effects of distortion are still further diminished, because in this case we do not approach the edges of the lens' field. In fact, single lenses have been used in some most successful architectural interior work.

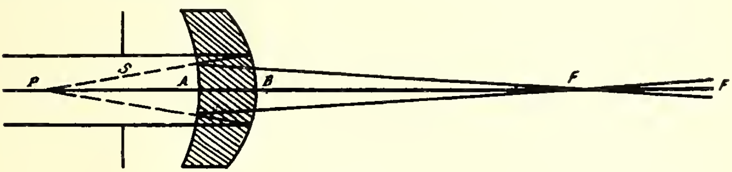


FIG. 45.

[12] *Flare Spot.*—When using a lens at small aperture on a brightly lighted landscape you have no doubt got a result something like fig. 44. This is flare spot, and it is caused by light *reflected from* the lens as distinguished from light *refracted by* the lens. As we pointed out in Chapter I., all objects reflect some light, and the way in which this reflected light causes flare spot will be understood

from fig. 45 : A B are the two surfaces of a lens, and S the diaphragm. When the light falls on surface A, most of it is refracted to the focus F : part is reflected by the surface and never reaches the plate ; part is refracted back into the lens and is reflected by B back to A, where it divides into two further subdivisions. One is reflected by A and forms an image of the point from which the rays first came at *p* ; the other comes to a focus at F, where its rays cross and produce a disc which is the image of the diaphragm. As the figure shows, the size of the flare spot depends on the diameter of the diaphragm, and the position of F on the distance of the diaphragm from the lens. Hence a very small alteration in the position of the diaphragm can remove the flare spot by bringing F so much closer to the lens that the image, greatly diminished in intensity, is spread over the whole plate. Flare spot occurs with large apertures as with small, but practically only the latter show it, for the reason that the longer exposure gives the flare spot image (which is just as bright whatever stop is used) time to affect the plate more strongly. See also pages 90 and 167.

CHAPTER V.

DEPTH OF FOCUS. DEPTH OF FIELD. FIXED FOCUS.

[1] *Great confusion* exists in the use of these terms. We will therefore explain what practical meaning we can attach to the terms. Let us first give some rough practical definitions and qualify them afterwards.

Depth of Focus is the distance the ground glass can be moved to and fro without any single object becoming visibly unsharp. As every photographer knows, this permissible racking increases as the lens is stopped down. "Depth of focus" in this sense is evidently measured in most cases by a distance ranging from a fraction of an inch to, at the most, a few inches.

[2] *Hyper-focal Distance.*—Suppose a lens focussed on an object a great way off—*i.e.* an object the rays from which are parallel when they reach the lens. Other objects nearer to the lens will also appear fairly sharp. The distance of the nearest of these objects from the lens is the *hyper-focal distance,* which in ordinary cases is some fifty times or so the focal length of the lens.

[3] *Depth of Field* is the distance between two objects lying at different distances in a straight line from the lens. Unlike "depth of focus" it amounts to feet instead of inches, in ordinary cases. Depth of field is called depth of focus by many photographers. We can now define more exactly what we mean by these three things and see what they depend upon.

[4] *Depth of Focus.*—Under "circle of confusion" we saw that there is no hard and fast distinction between sharpness and unsharpness, but that for convenience an arbitrary standard of sharpness has been adopted by a circle of confusion of $\frac{1}{100}$ of an inch in diameter ([5], Chapter I.). If we approach the "depth of focus" of a lens by way of the pinhole we shall get a clear notion of what it is.

A pinhole of $\frac{1}{100}$ of an inch diameter forms an image of a distant scene in circles of this diameter. Evidently, however, if the plate be

moved towards or away from the pinhole the circles making up the image will always be the same size. In other words, the pinhole has immense depth of focus. But it is not so with a lens, because here the bundles of rays reaching the plate are convergent and the plate may receive an unsharp image according as it is in front of or behind the focal plane (*a* and *b* in fig. 46). But by inserting a small dia-

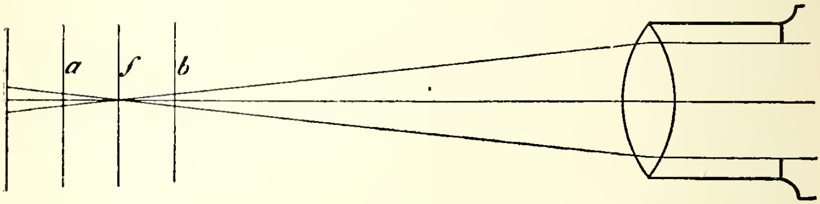


Fig. 46.

phragm we may narrow down the beam of light so that the diameter of the beam is no greater than $\frac{1}{100}$ of an inch at *a* or *b*. When this is the case the depth of focus of the lens is the distance from *a* to *b*. Fig. 47 shows that the depth of focus increases with the focal length but decreases as the aperture becomes larger, which means, of course,

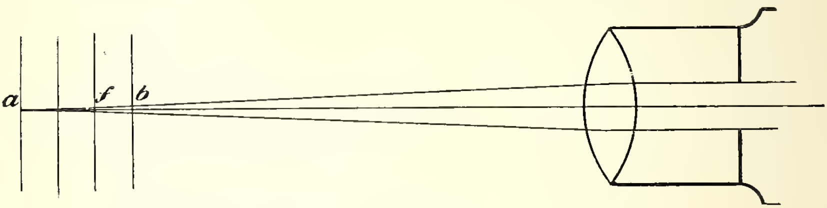


Fig. 47.

that depth of focus is fixed by the "working aperture." It does not follow from this that the depth of focus of every lens that works at f8 is therefore precisely the same. This would be true if all lenses had the same kind of field. But they have not, and as we form our pictures all over the plate and not merely at the centre, the practical difference is often very great. In the case of a lens with a curved field the depth of focus gets less towards the edges of the field. Another fact, too, may mislead: an inferior lens may seem to have much greater depth of focus than one which is better, simply because the first does not give a sharp image in any position of the ground glass. A lens which gives critical definition in one plane has to stand a severer test than one which has a certain amount of spherical aberration.

[5] *Fixed Focus.*—The distance from the camera at which objects

can be sharply focussed when the lens is set for distant objects is what most workers have in mind when speaking of "fixed focus." Certain cameras enable much closer objects to be focussed than do others. In other words, the hyper-focal distance (which is a more appropriate expression than "fixed focus") is less. It is "the distance from the camera to which an object, which has been sharply focussed when at an infinite distance, can be brought without becoming visibly unsharp." It depends on the focal length of the lens, the stop used, and the size of the disc of confusion which the operator is prepared to allow. We assume the conventional $\frac{1}{100}$ of an inch mentioned above merely because we can then show how the hyper-focal distance is calculated. We will first show how a practical rule which can be applied by ordinary arithmetic can be

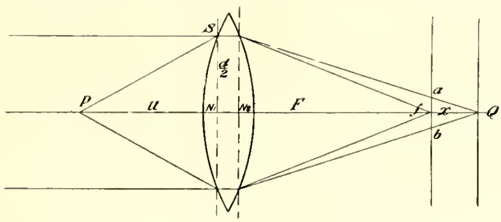


FIG. 48.

deduced from first principles. In fig. 48 let the parallel rays from an object at an infinite distance be brought to a focus at f. Then fN_2 is the focal length of the lens. Suppose now that P represents the point to which this object can be brought such that its focus is Q but that the disc of confusion which is produced through it being focussed in the plane of f is just $\frac{1}{100}$ of an inch in diameter—*i.e.* $ab = \frac{1}{100}$ of an inch and $fa = \frac{1}{200}$ of an inch. Q is the point at which the rays from P come to a focus, so that PN_1 and QN_2 are conjugate focal distances. Let us call PN_1, u and Qf, x. If we call the diameter of the stop d, we may represent this in the diagram by calling N_1S, $\frac{d}{2}$.

Now by Euclid

$$\frac{x}{af} = \frac{F+x}{\frac{d}{2}};$$

or,

$$\frac{F+x}{x} = \frac{\frac{d}{2}}{af}.$$

Now because P and Q are conjugate foci

$$\frac{1}{F+x} + \frac{1}{u} = \frac{1}{F},$$

which is the same thing as

$$\frac{1}{u} = \frac{1}{F} - \frac{1}{F+x} = \frac{F+x-F}{F(F+x)} = \frac{x}{F(F+x)}$$

$$\therefore u = F\frac{F+x}{x}.$$

But as we showed above,

$$\frac{F+x}{x} = \frac{\frac{d}{2}}{af}$$

$$\therefore u = \frac{F\frac{d}{2}}{af} = \frac{F \cdot d}{2\,af}.$$

This gives us the answer, viz., that hyper-focal distance is equal to

$$\frac{\text{focal length} \times \text{diameter of stop}}{\text{diameter of circle of confusion}}.$$

We can express this in a more convenient way. The working aperture-ratio of a lens (*f*8, *f*11, etc.) which we will call r (*e.g.* *f*8, *f*11, *fn*) is

$$r = \frac{F}{d}$$

$$\therefore d = \frac{F}{r}.$$

Therefore in formula, hyper-focal distance $= \dfrac{F \times F}{r \times \frac{1}{100}}$ for standard circle of confusion: or in words, multiply the focal length by itself, then by 100, and divide the result by the f number, and by 12 to bring it to feet.

Example.—Required hyper-focal distance of 4-inch lens at f 16.

$$\frac{4 \times 4 \times 100}{16 \times 12} = 8 \text{ ft. } 4 \text{ ins.}$$

The practical importance of these calculations is that if we set a lens in focus for the distance in the landscape, the nearness to the camera of objects which we can still get in focus is determined (1) by the focal length of the lens—the shorter the focal length, the nearer the object may be; and (2) by the diameter of the stop: the smaller

the stop, the nearer the object may be. These are facts of special importance to hand camera workers.

The following table. gives the hyper-focal distances for various focal distances and apertures.

TABLE OF DISTANCES at and beyond which all objects are in focus and may be considered as situated in one plane.

Focal length of lens in inches.	Diaphragm Apertures. (*F* Nos.)													
	F/4.	F/5·6.	F/6.	F/7.	F/8.	F/10.	F/11.	F/15.	F/16.	F/20.	F/22.	F/32.	F/44.	F/64.
	Number of feet distant after which all is in focus.													
4	33	24	22	19	17	13	12	9	8	7	6	4	3	2
4¼	38	27	25	21	19	15	14	10	10	8	7	5	3½	2½
4½	42	30	28	24	21	17	15	11	11	8½	7½	5½	4	3
4¾	47	34	31	27	24	19	17	12	12	9½	8½	6	5	3
5	52	36	35	30	26	21	19	14	13	10½	9½	6½	5½	3½
5¼	57	40	38	33	28	23	21	15	14	11½	10½	7	5½	3½
5½	63	45	43	36	31	25	23	17	15	12½	11½	7½	6	4
5¾	68	50	46	38	34	27	25	18	17	13½	13	8½	6½	4
6	75	54	50	42	38	30	28	20	19	15	14	9	7	4½
6¼	81	58	54	46	40	32	29	22	20	16	15	10	7½	5
6½	87	62	58	50	44	35	32	23	22	17½	16	11	8	5½
6¾	94	67	63	54	47	38	34	25	24	19	17	12	8½	6
7	101	72	68	58	51	40	37	27	25	20	18	12½	9	6
7¼	109	78	73	62	54	44	39	29	27	22	20	13½	10	6½
7½	117	83	78	64	58	47	42	31	29	24	21	14½	10½	7
7¾	124	90	83	71	62	50	45	33	31	25	22	15½	11	7½
8	132	96	88	76	68	52	48	36	32	28	24	16	12	8
8¼	141	100	94	80	71	56	51	37	35	29	25	17½	12½	8½
8½	150	104	100	84	76	60	56	40	38	30	27	19	13½	9
8¾	156	111	104	89	78	63	57	42	39	32	29	20	14	10
9	168	120	112	96	84	67	61	45	42	34	31	21	15	10½
9¼	180	127	116	101	90	71	65	47	45	35	32	22	16	11
9½	190	133	125	107	95	75	68	50	47	37	34	24	17	12
9¾	197	141	131	113	99	79	72	52	50	39	36	25	18	12½
10	208	148	140	120	104	83	75	55	52	42	38	26	19	13

[6] *Depth of Field* is allied to the question of hyper-focal distance, and is what is meant by most photographers when they talk about "depth of focus." Suppose we focus on some object, A, at a certain distance—not very great—from the camera, we know that we shall get objects nearer and more remote than *a*, also reasonably sharply defined. Theoretically, as we know, this is impossible: practically, as we have seen, it is the prevailing condition in camera work. If

we get, say, two objects, B and C, on either side of A approximately sharp, the distance between B and C is the depth of field.

Depth of field

LENS . . . . B A C

By a geometrical construction somewhat similar to that employed under hyper-focal distance we can show that there exists a certain relation between the distance of A from the lens (which we will call a) and the distances of B and C from the lens (which we will call b and c). This relation is

$$b = \frac{h \times a}{h + a};$$

$$c = \frac{h \times a}{h - a};$$

where h is the hyper-focal distance for the lens and stop in use. The distance c–b is evidently the depth of field, and is equal to

$$\frac{h \times a}{h - a} - \frac{h \times a}{h + a} = \frac{2h\ a^2}{h^2 - a^2}.$$

[7] *Depth of Focus at close quarters.*—These formulæ hold good only when the focal length of the lens is small in comparison with a, say when equal to one-twentieth or one-fiftieth of a. In order to calculate depth of field for objects nearer to the camera the following more accurate formulæ are to be used:—

$$b \text{ (distance of nearer object B)} = \frac{h \times a}{h + (a - f)};$$

$$c \text{ (distance of further object C)} = \frac{h \times c}{h - (a + f)},$$

f being the focal length of the lens in each case.

[8] *Examples of Depth of Focus.*—In order to explain in figures and diagrams what these formulæ mean we will work out four examples. They involve only simple arithmetic, and the reader who will carefully follow them will be well on the road towards mastering "depth of focus."

Problem I.—Suppose with lens of 5 ins. focal length working at f6 we focus sharply on an object, A, 9 ft. away. To find the distances from the camera of objects before and behind A which will be reasonably sharp—

Hyper-focal distance for 5-inch lens at f6 equals 35 ft.

Therefore distance of nearer object (B) is

$$\frac{35 \times 9}{35+9} = \frac{315}{44} = 7 \text{ ft. (and } 2\tfrac{1}{2} \text{ ins.).}$$

Distance of further object is

$$\frac{35 \times 9}{35-9} = \frac{315}{6} = 12 \text{ ft. (and 1 in.).}$$

Therefore depth of field is 5 ft.

Problem II.—With same lens and aperture as before suppose we focus on an object, A, 20 ft. away. To find distances from camera of objects before and behind A which will be reasonably sharp.

As before, hyper-focal distance is 35 ft.

Distance of nearer object is

$$\frac{35 \times 20}{35+20} = \frac{700}{55} = 12{\cdot}7, \text{ say } 12\tfrac{1}{2} \text{ ft.}$$

Distance of further object is

$$\frac{35 \times 20}{35-20} = \frac{700}{15} = 46\tfrac{1}{2} \text{ ft.}$$

Therefore depth of field is 34 ft.

Problems III. and IV.—Suppose with a lens of 10 ins. focal length working at *f*6 we focus sharply on an object (III.) 9 ft. away and (IV.) 20 ft. away. To find distances from camera, of objects before and behind A, which in each case will be reasonably sharp. Hyper-focal distance is 140 ft.

III.—Here focal length is not small compared with the distance of the object—it is only $\frac{1}{11}$ of the distance—so we must use the more accurate formulæ.

Therefore distance of nearer object is

$$\frac{140 \times 9 \times 12 \text{ ft.}}{140 \times 12 + (108 - 10)} = 8 \text{ ft. } 6.$$

Distance of further object is

$$\frac{140 \times 9 \times 12}{140 \times 12 - (108 - 10)} = 10 \text{ ft. } 8.$$

Depth of field is therefore 2 ft. 2.

IV.—Distance of nearer object is

$$\frac{140 \times 20}{140+20} = \frac{2800}{160} = 17\tfrac{1}{2} \text{ ft.}$$

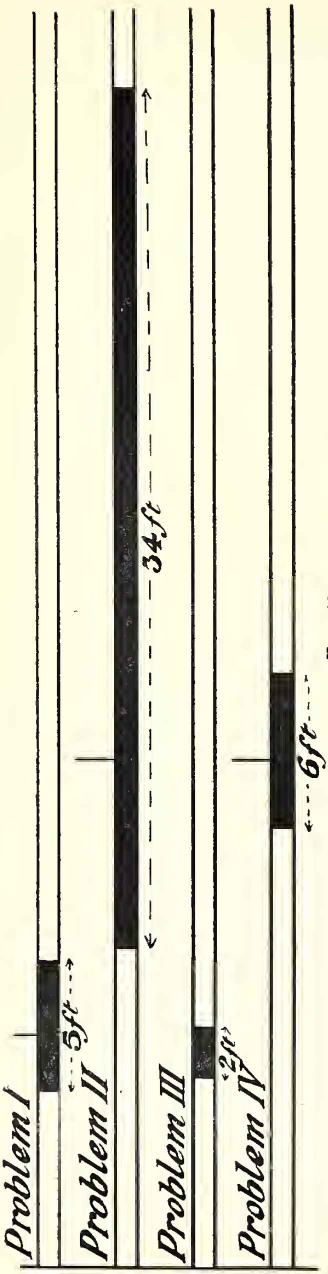


Fig. 49.

Distance of further object is

$$\frac{140 \times 20}{140 - 20} = \frac{2800}{120} = 23\tfrac{1}{2} \text{ ft. nearly.}$$

Therefore depth of field is 6 ft. approximately.

Let us tabulate these results.

Distance of object focussed.	5-inch lens at *f*6.	10-inch lens at *f*6.
	Depth of Field.	
9 ft.	5 ft.	2 ft. 2 ins.
20 ft.	34 ft.	6 ft.

In fig. 49 we show these results diagrammatically. The black bands show the depth of field when the lens is focussed on points 9 ft. (I. or III.) or 20 ft. (II. and IV.) distant.

Comparing I. and II., we see how depth of field diminishes as the object focussed approaches the camera. Comparing I. and III. and II. and IV. we see the relative depths of field.

[9] *Depth of Field applied* when an object at the same distance is focussed into lenses of different focal length. These diagrams explain what so many beginners find a great difficulty in understanding—why a lens of short focal length makes hand-camera work easier than when one of great focal length is used. The field in which different objects might be placed and yet appear sharp is much greater in the case of lenses of short focus, even when the distances of the object in the two cases are such that the same size of image results.

Size of image is proportional to focal length, but depth of field increases as the focal length is diminished, and not in a direct proportion but in a constantly increasing ratio. The reader will thus see that depth of field is dependent on focal length and working aperture—the two factors which determine hyper-focal distance—and also on the distance of the objects focussed from the camera.

For work in which focussing is done by scale it is sometimes useful to have a table of depths of field worked out for the particular lens and stop one is using, and for the various distances from the camera of the most sharply defined object.

A table calculated by the simple method instanced above is sufficiently accurate for the obviously rough and ready estimation of distances.

Table of Depths of Field for lens of 5 ins. focal length, calculated on the basis of a disc of confusion of $\frac{1}{100}$ of an inch.

F 6.			*F* 8.			*F* 11.			*F* 16.		
b	*a*	*c*	*b*	*a*	*c*	*b*	*a*	*c*	*b*	*a*	*c*
	6			6			6			6	
	8			8			8			8	
	10			10			10			10	
	15			15			15			15	
	25			25			25			25	
	30			30			30			30	

In compiling such a table for himself the possessor of a hand camera would of course insert the figures marked on his focussing scale under *a* and calculate the distances *b* and *c* from them.

CHAPTER VI.

SPHERICAL ABERRATION. ASTIGMATISM. COMA. CURVATURE OF FIELD.

[1] *Spherical Aberration.*—In the preceding diagrams we have shown rays passing through the centre and through the margins of the lens, as coming to a focus at the same point (*e.g.* fig. 19). But really a lens with spherical surfaces will not do this accurately. It bends the rays passing through the margins more than those passing through the centre—*i.e.* the focus (B) of the marginal rays (fig. 50) is nearer the lens than the focus (A) of the axial rays. This means that when we place ground glass at B we get a fuzzy image due to the still converging axial rays, and if we place it at A we get a fuzzy image

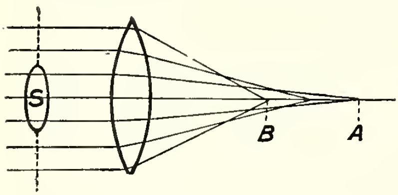


FIG. 50.

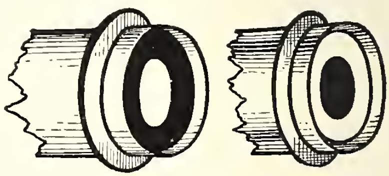


FIG. 51.

due to the axial rays which crossed at B. Figs. 52 and 53 show that this explanation of spherical aberration is correct.

Fig. 52 was taken with a lens in which the ring shown in fig. 51 was fixed, only the axial rays thus forming the image.

Fig. 53 was taken without the focus being at all altered, but the ring was replaced by a disc (fig. 51) which permitted only marginal rays to pass. Result, a fuzzy image. This teaches us two things:—(1) That we may get rid of spherical aberration by stopping down the lens. As seen in fig. 50 the stop S cuts out the marginal rays and allows only the central rays to pass. (2) That if our lens suffers from spherical aberration we must focus with the stop which we are going to use. If we focus with a large aperture we may get the image from the marginal rays, and on stopping down and cutting these off, obtain

a fuzzy image from the central rays. A lens which at large aperture is free from spherical aberration is called "aplanatic."

Spherical aberration is minimised by the optician by balancing it with negative spherical aberration. The lens to be corrected is combined with one which bends the central rays more than the marginal. The choice of suitable curves enables this to be done. Spherical aberration depends to a slight extent on other things than the curves of the glasses: it varies with the refractive index of the glass and

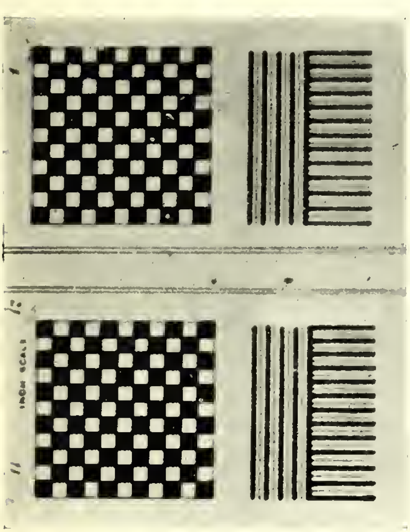


Fig. 52.

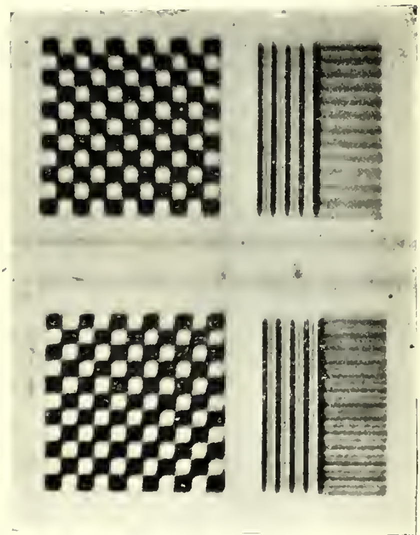


Fig. 53.

with the color of the light. See Conrad Beck, *Journal of the Society of Arts*, Feb. 2nd, 1889.

[2] *Astigmatism.*—When rays fall upon the lens not parallel with the axis, as in fig. 35, but obliquely to the lens, as in fig. 36, this defect is liable to occur. Practically astigmatism means the inability of a lens to give, near the edge of the plate, an image of an object containing horizontal and vertical lines in which both are sharp at the same time. Either the horizontal lines will be sharp and the vertical fuzzy (fig. 54), or *vice versa* (fig. 55). These are taken with an ordinary cheap wide angle lens; fig. 55 with a high grade anastigmat; all are enlarged. It is easier to show what astigmatism is, than to explain why it is.

Of the various attempts at making the matter clear none is so admirable as Professor Dr. Miethe's, which we quote here from his *Photographische Optik* :—

"Imagine $p\ q$, $p'\ q'$ (fig. 57) to represent a lens in perspective. $p\ p'$ and $q\ q'$ are its two diameters: $p\ p'$ is supposed to lie in the plane of this printed page, $q\ q'$ lies in a plane perpendicular to it, *i.e.* q' is supposed to be nearer to the reader and q further away behind $p\ p'$. (See fig. 57.) The curved lines dotted on the underside show the sections of the lens at its two diameters. Inagine now a few rays b, a, a', a'', b'', falling on the lens from a point at an infinite distance and situated to the right of the centre of the lens so that the rays fall slantwise all over the surface of the lens and give an image somewhere towards the left hand edge of the plate. We are

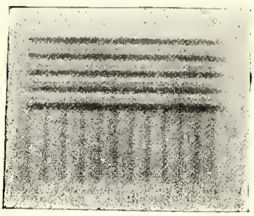


FIG. 54.

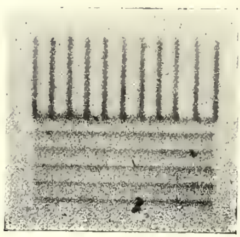


FIG. 55.

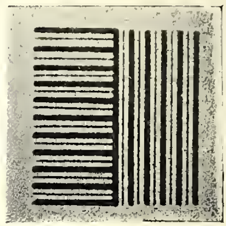


FIG. 56.

going to see how it is that this point appears as a short horizontal bar in one position of the plate and as a similar vertical bar in another. We take the rays b, a' and b'' as typical of rays falling across the diameter of the lens and in the plane of the page, and call them 'rays in the perpendicular plane,' and $a\ a''$ as rays in a plane oblique to the plane $p\ q$, $p'\ q'$ of the lens. We call these 'rays of the oblique plane.' The ray a' passing through the centre of lens, and which we call the principal ray, belongs to both sets. Fig. 58 shows the two perpendicular planes containing these rays.

"Now, construction or calculation will show us that the focus of the rays in the perpendicular plane is not the same as that of rays of the oblique plane. This is because the action of the lens on the oblique rays occurs in two distinct phases: first, the bending of the plane of the rays at the surface of the lens, and secondly, the bringing to a focus of the rays in the plane, after bending. In the case of the rays of the normal plane these two effects take place in the same plane, but the two phases take place in different

planes perpendicular to each other, and are independent of each other.

"Take f for the focus of rays of the normal plane, and f' for that of rays of the oblique plane. In fig. 57 we see that the rays b and b'', as well as all intermediate rays, converge at f, whilst rays a and a'' pass outside this focus and meet f'. If therefore we intercept the oblique rays at f we get a section which is a straight line, $e\,e'$, perpendicular to this page, so that if we place

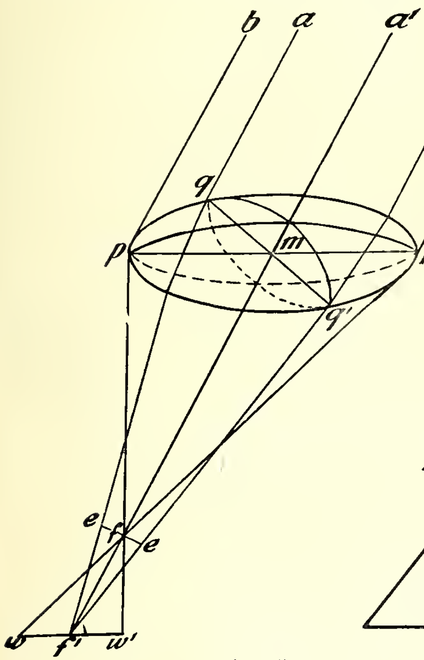


FIG. 57.

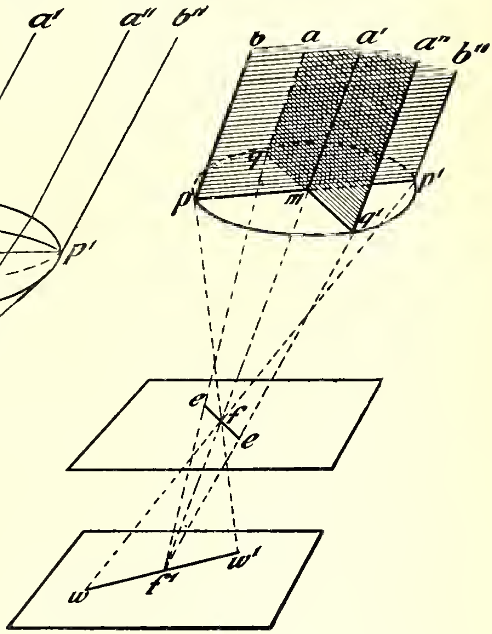


FIG. 58.

the ground glass at f we get—not a luminous point—but a line perpendicular to that joining the centre of the ground glass and the point f.

"But we see from the fig. 58 that if we place the ground glass at f'—*i.e.* at the focus of the oblique rays—the normal rays which have diverged after passing through the focus f, form a luminous line parallel to $p\,p'$, and therefore lying in the plane of this page. This means, of course, that our point appears as a line parallel to the line joining f' to the centre of the ground glass. If we take points

between these two positions we get a series of images of a bright point such as is shown in fig. 59."

Astigmatism does not exist at the centre of the field. It increases as we pass to the margins, and it is possible to draw a curve (of minimum astigmatism) which shows the kind of field given by a lens.

[3] *Coma* is a defect somewhat resembling astigmatism in its results. Only single lenses and portrait lenses are liable to it. It arises from a kind of spherical aberration (see above) which will be best understood if we quote again from Professor Miethe:—

"In order to get an idea of how coma is caused let us consider the case of a bundle of converging rays falling on the plate of glass in fig. 60. Their inclination is such that if the plate were not there they would meet at f. Owing to the interposition of the glass the

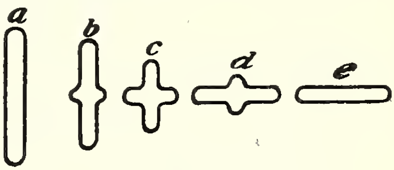


Fig. 59.

rays are bent at the points a' b' c' and d', but they do not meet at the point f' as they would do were the plate thick enough. On the contrary, the focus of two neighboring rays differs from that of the next pair of rays. This is a phenomenon which can be proved by construction when the rays are sufficiently oblique and the index of refraction is high enough. The same thing happens at the second surface of the plate, so that the rays a and b meet at f'', b and c at f''', and c and d at f''''. If we place a ground glass at f'' we see a luminous image which spreads leftwards from f'' in the shape of a comet, the brightness of which decreases as it is distant from f''; this decrease being, of course, due to the spreading out of the other rays which have passed through their foci.

"Coma is produced in lenses in a similar way. Thus, ff' (fig. 61) being the optical axis of the lens, the parallel rays falling upon the lens do not come to a single point on the other side: a and b meet at p, b c at p', c and d at p'', and d and e at p'''.

"If f is the focus of axial rays, we shall obtain a sharp image at the edge of the field only by cutting off the rays forming the coma.

If we place a diaphragm $q\,q'$ in front of the lens, only the rays between d and e can reach the lens. The coma therefore disappears, since these rays practically come to a focus at p'''. If we place the diaphragm nearer to the lens ($r\,r'$) this focus will be p'' and the coma will in like manner disappear. Moreover, p'' being in the focal plane the field of definition becomes flat. It will thus be understood how this fact determines the position of the diaphragm in simple landscape lenses; and also that the coma is only completely eliminated by the diaphragm when the latter is very small.

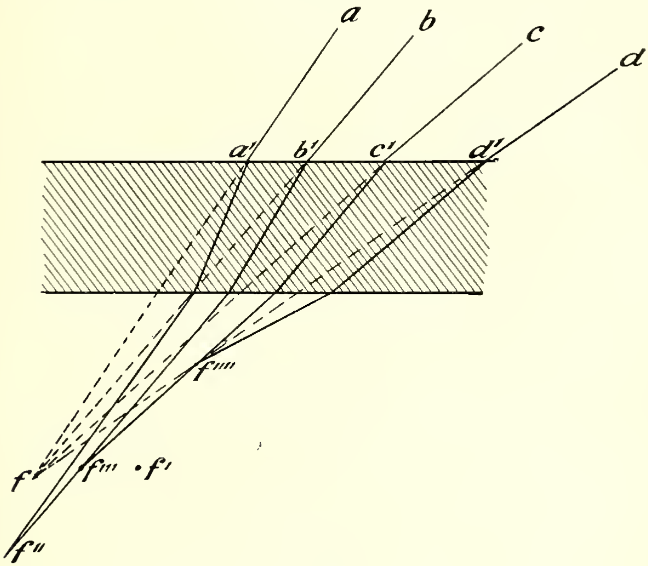


Fig. 60.

Other things remaining the same, coma increases with the obliquity of the luminous pencil and disappears entirely at the centre of the field."

A number of means of diminishing or entirely removing coma exist in addition to the diaphragm which we have just mentioned, and which occasions such a great loss of light.

In simple landscape lenses it is only possible to entirely remove the coma at the expense of the correction of astigmatism or of flatness of field. In practice both coma and astigmatism are eliminated at the same time by choice of suitable glasses and curves, a medium diaphragm being retained in the lens.

Coma is always accompanied by astigmatism, so that much bad definition is due to both of these causes.

[4] *Curvature of field* is a very undesirable quality. Some lenses have the saucer-shaped field shown in fig. 62, others a convex field. The result is that it is impossible to obtain an image of a flat object in focus at the centre and edges of the field at the same time. In

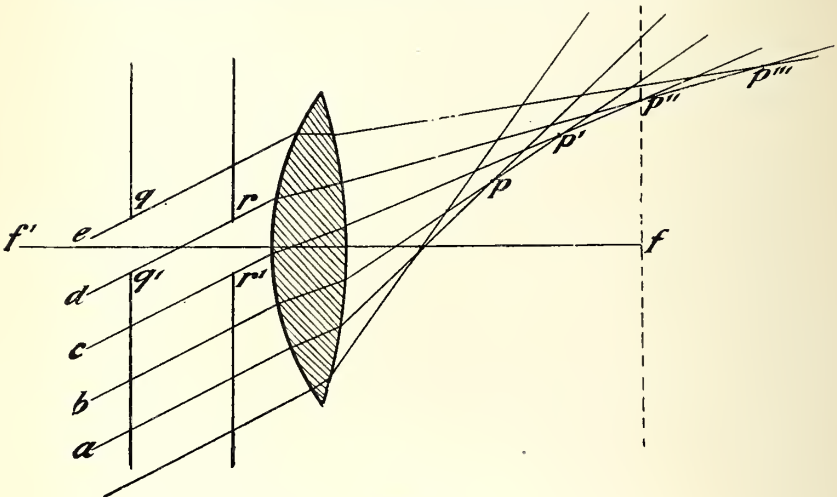


FIG. 61.

the case of double lenses curvature of the field is reduced by separating the lenses, but when this is done, astigmatism increases. Until the introduction of the new Jena glasses it was not possible to get very flat field lenses free from astigmatism. See [9], Chapter VII.

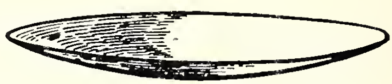


FIG. 62.

[5] *Lack of covering power* is a defect for which curvature of field is often responsible. A lens with a field of good definition of a certain diameter will cover any plate which can be placed inside that circle, but it will not cover a larger plate, nor will it completely cover its normal plate if the lens is not opposite the centre of the plate. If the lens is moved up or down, or to the left or right, the field of definition is moved away from the plate and some parts are bound to

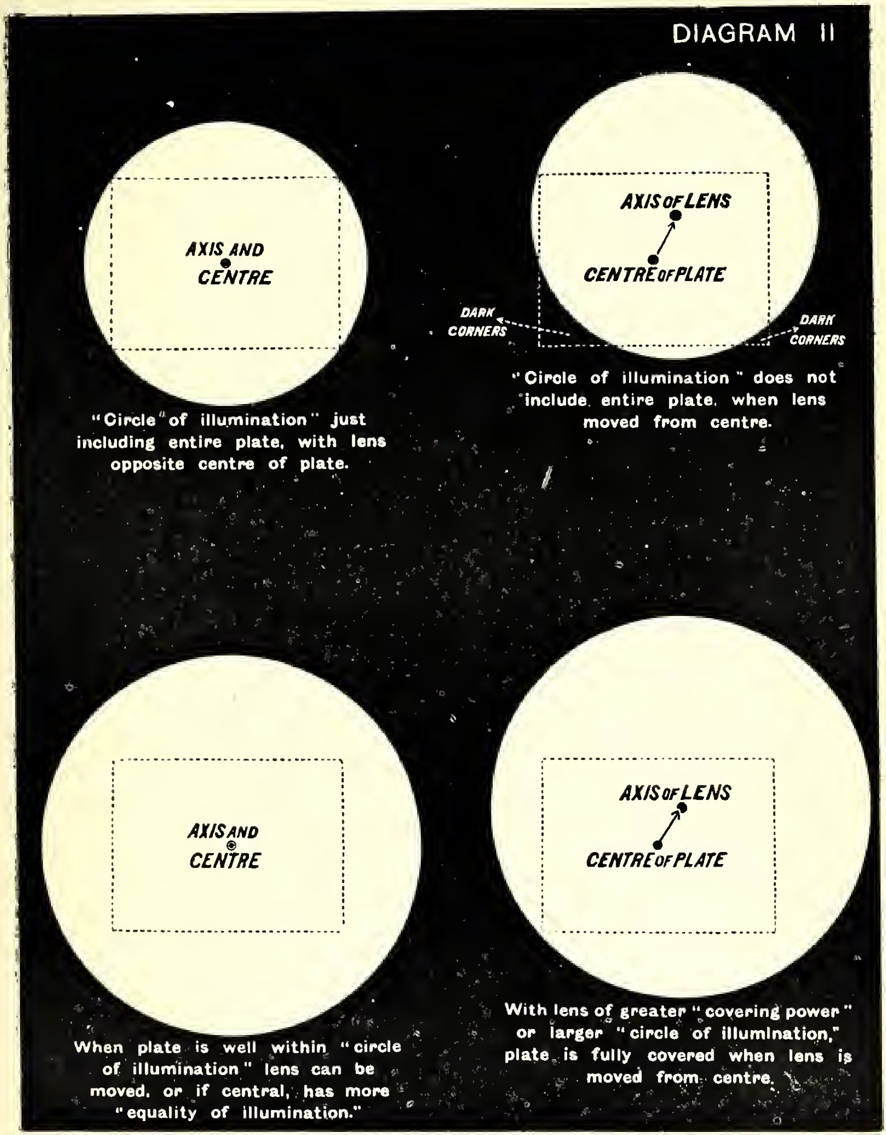


FIG. 63.—From *Simple Guide to the Choice of a Photographic Lens*, by T. R. Dallmeyer.

suffer. (See fig. 63.) The covering power of lenses varies greatly, though how the optician obtains fine definition over a wide field we cannot now discuss. The practical lesson is:—The larger the circle covered by a lens of given focal length the better, because the lens can be moved about on the camera-front without fear of ill-defined corners in the negative, and also because the lens can be used to cover a larger plate. See *Angle of View*, [2], Chapter III.

CHAPTER VII.

CHROMATISM. NEW ACHROMATS AND MODERN ANASTIGMATS.

[1] *Non-achromatism.*—A lens is "achromatic" when it brings two or more of the spectrum rays (red, orange, yellow, green, blue and violet) of which white light is composed, to the same focus. Every photographic lens ought to be achromatic, and most of them are. We shall understand what non-achromatism means in practice if we go back to the prism.

When we spoke of a prism "refracting" light, we said that it also "dispersed" light. Refraction is the bending of a ray as a whole (fig. 7); dispersion arises from the fact that of the various spectrum rays the blue and violet (*i.e.* the chemical rays, which affect the plate most and the eye least), are bent more than the red and orange rays, which affect the eye more than the plate (fig. 64). A lens which behaves like a prism does the same, and we see in fig. 65 a greatly exaggerated diagram of what happens. The violet rays being much more refrangible (bendable), are brought to a focus nearer to the lens than are the yellow, orange and red rays. What does this mean in practice? In fig. 66, which was prepared with a view to exaggerate the effect, the contents bill was inclined to the lens and the centre focussed at the word " bichromate," a non-achromatic lens being used. Since the yellow rays are those most visible to the eye, the image focussed is formed by these (visual focus). But the plate sees the blue and violet rays, and therefore receives the blurred images due to these. The sharp image in the lower part is due to the lines being nearer to the lens, the rays being thus brought to a focus so much further back (see "Conjugate Foci," [11], Chapter II.) that the violet rays fall on the focal plane.

The following, in the barest outline, is the method by which this defect is cured:—The power of glass to disperse light—*i.e.* to spread it out into a colored band—is quite distinct from its power to bend

the ray as a whole. Flint glass has a much greater dispersive action

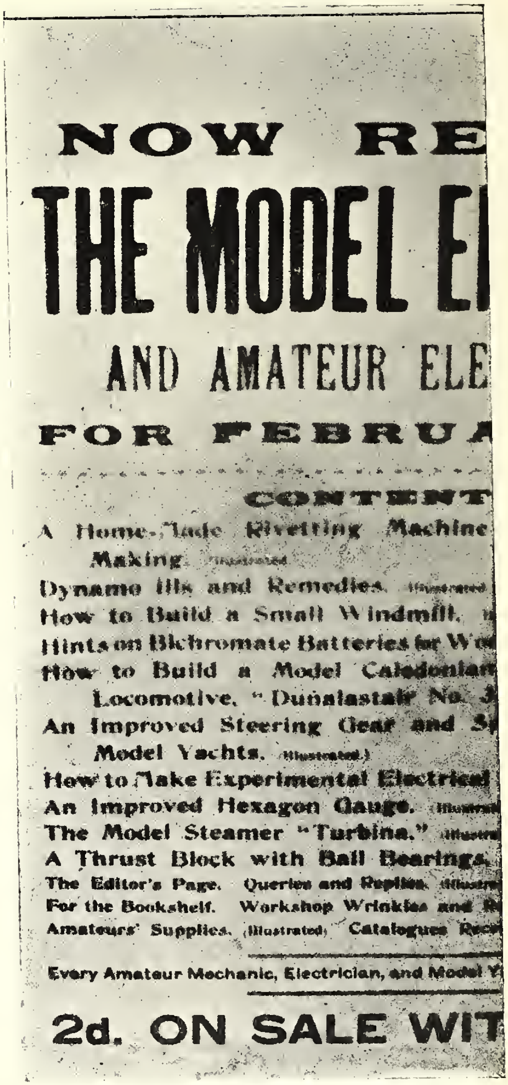


Fig. 66.

than has crown glass of equal refractive power. Hence by combining

a convex lens of crown glass with a *concave* flint-glass lens we can bind up the spectrum and still leave a residue of refractive power.

Bearing the above brief and incomplete explanation in our minds we may pass to consider the achromatising of a lens in a little more detail. We shall find that it is not quite so simple as might be supposed.

[2] *Dispersion.*—When a ray of sunlight is cut down to a slit by passing through a diaphragm and is then allowed to fall on a prism,

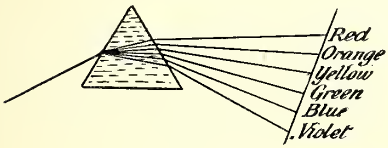


Fig. 64.

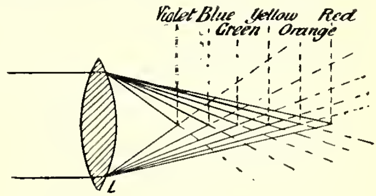


Fig. 65.

it is, as we know, spread out into a colored band—the spectrum. In the spectrum a number of thin dark lines can be found. These Fraunhofer lines (so called after their discoverer) afford a means of labelling, as it were, the various parts of the spectrum. For convenience in this respect they have been lettered, so that when we speak of the B line we know exactly what part of the red we mean; or when we refer to the F line we know that we mean a certain spot at the green end of the blue. (See fig. 67.) The relative positions

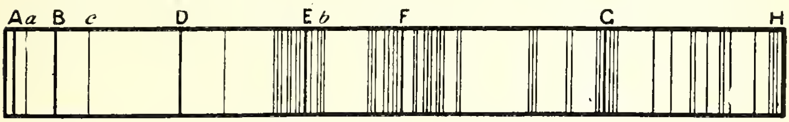


Fig. 67.—The solar spectrum.

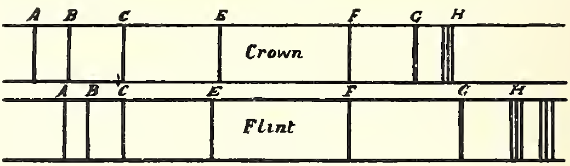
of these lines to one another enable us to show that the perfect achromatising of a single lens by a second lens as described above cannot be done in practice.

[3] *Irrational Dispersion.*—Figs. 68 and 69 show side by side two spectra of same light: one (fig. 68) with a crown glass and the other (fig. 69) with a flint glass prism. The spectra have been adjusted so that the lines C and F coincide, and it will be seen that none of the other lines exactly coincide, the prism of crown glass spreading out the red end of the spectrum at the expense of the blue, and the prism of flint spreading out the blue end of the spectrum at the expense of the red. This fact prevents all the colors of the spectrum

being united to the same focus by a single correcting lens, and this unfortunate behaviour of a prism is called the "irrational dispersion."

[4] *Secondary Spectrum.*—The optician therefore arranges to bind up two colors, and he selects of course the color to which the eye is most sensitive and that to which the plate is most sensitive. These are the green and yellow about the line D, and violet-blue near to the line G. But with only two glasses of flint and crown he must let the rays of other colors which are not perfectly recombined take their chance. A lens which thus unites two colors is said to be "achromatic." The colored rays which still remain are said to form a "secondary spectrum" or residual spectrum; and although for most practical purposes this residual spectrum is of no importance, it is very desirable for certain purposes to have a lens in which much more of the spectrum is brought to a focus.

[5] *Apochromatic.*—The addition of another glass enables this to be done, light of another color being combined with yellow and blue



FIGS. 68 and 69.

already brought to the same focus. Lenses such as this, which are now made commercially, are known as "apochromatic."

An apochromatic lens brings any of three colors to the same focus, which is sufficient for almost any photographic purpose.

[6] *Tertiary Spectrum.*—There are still other rays uncombined—*i.e.* there is a "tertiary spectrum"—but the most delicate photographic work would scarcely serve to show the existence of this residual chromatism.

[7] *Old and New Achromats.*—We must now endeavor to appreciate the difference between what are known as "old" and "new" achromats. And to do this we will first consider what is understood by these terms.

We have already seen that in producing an achromatic lens we combine a positive lens with a negative lens which will bind up two colors of the spectrum produced by the first, the negative lens being less refractive than (though equally dispersive as) its colleague. At the same time the lens-maker has to remove spherical aberration,

which he does by selecting suitable curvatures of the two lenses. Now with the glasses which were available up to the time of Dr. Abbé, two typical forms of lenses have been used. They are shown in figs. 70 and 71.

[8] *Old Achromats.*—Fig. 70 consists of a bi-convex crown with a bi-concave flint. With the convex side of the crown glass towards the light it gives sharp images at a comparatively large aperture. Convex side to the light it gives an image which is less sharp in the centre but moderately sharp over a much larger field. Fig. 71 is a meniscus consisting of a positive meniscus of crown with a negative meniscus of flint: used concave side to the light it gives sharp definition over a fairly wide field.

Now although flint and crown glass differ in dispersion for equal

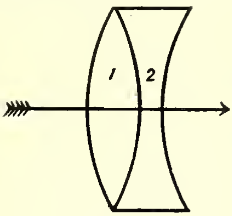


Fig. 70.

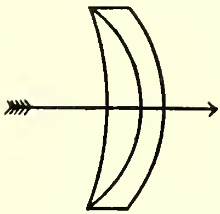


Fig. 71.

refraction, yet when the refraction of either is increased, the dispersion increases as well. This fact enforces certain conditions in the construction of an achromatic lens free from spherical aberration. Looking at fig. 70 we see that for the lens to be a converging lens at all, the focal length of 1 must be numerically less than the (negative) focal length of 2: in other words, 1 must be a more powerful lens than 2.*

Now if we want to make a high power (short focus) lens we must employ either deep curvature with moderate refractive power, or else moderate curvature and great refractive power. In either case we introduce errors of spherical and chromatic aberration, for the correction of which we must look to our negative lens. To produce compensation of the chromatic dispersion, we must use one lens of deeper curvature than the other, which very deepness of curvature makes it difficult to avoid spherical aberration.

* This follows from the formula $\frac{1}{F} = \frac{1}{f_1} \times \frac{1}{f_2}$, where f_1, f_2 are the focal lengths of 1 and 2, $F = \frac{f_1 \times f_2}{f_2 - f_1}$. Therefore for F to be positive, f_1 must be less than f_2.

Now the size of the circle of chromatic aberration is inversely proportional to the focal length of the lens—*i.e.* the color fringe around the image of a point is greater the shorter the focal length of the lens. The focal length of our positive lens is less than that of the negative. Therefore the chromatic aberration of 1 is greater than would be that of 2 if it possessed the same dispersive power. Hence to balance the chromatism of 1, the dispersion of 2 must be greater than that of 1; and, as we know that refractive power varies with dispersive power (though not proportionally), we see that we are forced to use a glass for the diverging lens which is also more refractive than the converging lens. Until the new Jena glasses were introduced this condition was the only possible one. Let us repeat it before we pass to the new achromat: with glasses in which dispersion rises and falls with refraction, an achromat must consist of a converging lens with both dispersion and refraction lower than those of the diverging lens.

[9] *New Achromats. Flat Fields.*—It was shown by Von Seidel that for a thin lens to have a flat field the following must hold good, viz.—

$$\frac{1}{\mu_1 \times f_1} + \frac{1}{\mu_2 \times f_2} = 0$$

$$i.e.\ \mu_1 f_1 = -\mu_2 f_2,$$

where f_1 and f_2 are the focal lengths of two elements and μ_1 μ_2 the refractivities of the glasses of which they are composed.

This is the same thing as—

$$\mu_1 \times f_1 = -\mu_2 \times f_2.$$

This formula shows two things—

(1) That the focal lengths of the two lenses must be of opposite signs —*i.e.* one lens is converging and one diverging; and

(2) The lens of shorter focal length must be made of glass of higher refractive index.

Let us contrast this with the condition for achromatism which we investigated above.

(1) Achromatism requires the more powerful lens of crown and the less powerful of flint—*i.e.* the converging lens must be of a glass of lesser dispersion than that of the diverging lens.

(2) Flatness of field requires the more powerful lens of flint and the less powerful of crown—*i.e.* the glass of converging lens must have a greater *refractivity* than that of the diverging lens.

We see that these are quite contradictory requirements. If we

satisfy condition (2) and get flatness of field, by taking for the converging lens a glass of greater refractivity than that used for the diverging lens, then we can only get achromatism if we can obtain along with this higher refractivity a less dispersion than that of the glass of *lower* refractivity. The glass technical laboratory of Jena has supplied glasses which enable this last condition to be realised.

[10] *Jena Glass.*—Let us first give and explain some of the data of a few glasses of the Fraunhofer and of the Abbe period.

Glass.	Refraction Index for D.	Index of Dispersion between C and F.	$v = \frac{n\text{D} - 1}{\Delta n.}$
Hard English crown .	1·518	·0086	60·2
Soft English crown .	1·515	·0090	57·2
Light flint . . .	1·571	·0133	43·0
Heavy flint . . .	1·620	·0171	36·2

	Refraction Index.	Mean Dispersion $\mu_F - \mu_c$.	$\frac{n\text{D} - 1}{\mu_F - \mu_c} = v.$
Light Phosphate crown	1·5159	·00737	70
Boro-silicate crown .	1·4967	·00765	64·9
Dense silicate flint .	1·7174	·02434	29·5
Densest silicate flint .	1·9626	·04882	19·7

Let us get some idea of the physical meaning of these figures and we shall then see their immense importance in the construction of the new achromats.

[11] *The refractive index* of any substance is a numerical expression of the refracting power of the substance towards light of a given part of the spectrum. The law of refraction (see fig. 72) is that when a ray of light passes into a denser medium it is bent towards the perpendicular to the surface of the medium.

Thus in fig. 72 r is called the angle of refraction and i the "angle of incidence"—that is to say, the angles which the refracted and the incident ray make with the perpendicular to the surface. A very simple construction decides the index of refraction. If we describe a circle with centre n and drop perpendiculars from the points a and b (where the incident and refracted rays cut the circle) upon the perpendicular to the surface, then the ratio of $a\,d$ to $b\,f$ (*i.e.* $a\,d$ divided by $b\,f$) is the index of refraction. In case of water the index equals 1·3 or 1·333, and is written $\mu_D = 1{\cdot}333$.

[12] *Dispersion,* the power of a substance to spread light into a spectrum, is measured much more simply. It is simply the difference between the refractive indices of rays of different color. For photographic purposes we are interested chiefly in the orange rays, which

form the visible image on the screen, and the blue rays which form the image on the plate. So we select the three Fraunhofer lines D, C, and F, and finding the refractive indices for the light which comes from the spectrum at these points we subtract one from another. The difference is the dispersion. We write it $\mu_F - \mu_C$. The third column contains figures which represent the refractivity for equal mean dispersion, or, in other words, the achromatic refractivity. These figures are obtained by dividing the refractivity of the various glasses (after subtracting the refractivity of air = 1) by the mean dispersion. They tell us the relative refracting powers of glasses all of which disperse white light to an equal amount. We can go back now and solve the problem we left.

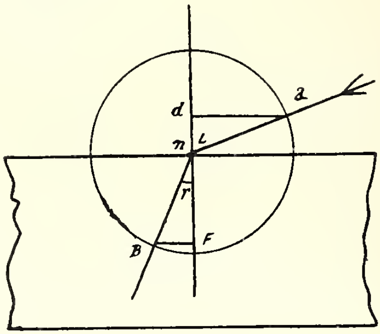


FIG. 72.

[13] *The Flat Field Achromat.*—Suppose we want to make a flat field achromat. We must, as we have seen, fulfil the following conditions.

(1) Positive lens must be more powerful (have shorter focus than negative), in order that resultant lens may be positive.

(2) The glass of converging lens must be of higher refractivity than that of the diverging lens.

(3) The glass of the converging lens must have less dispersion than the more feebly refracting glass of the diverging lens.

This cannot be done with the old English crown and flint glasses. But take the two following Jena glasses.

S 30, dense barium phosphate crown; refractive index, 1·5760; dispersion, ·0084.

O 381, crown of high dispersion; refractive index, 1·5262; dispersion, ·01026.

Taking S 30 for our converging lens we see that the dispersion of

the glass used for it is less than that of a lens which is not so refractive. Thus we see how the new glasses from the laboratories of Dr. Abbé have made possible the construction of these flat field achromats. We have now to show the use which has been made of these new achromats in the construction of the modern stigmatic lenses.

[14] "*New*" *Achromats in relation to Modern Lenses.*—The correction of a lens aberration is always a matter of compensation—*i.e.* of counter-

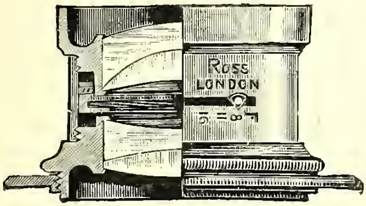


FIG. 73.—Series IIIA.

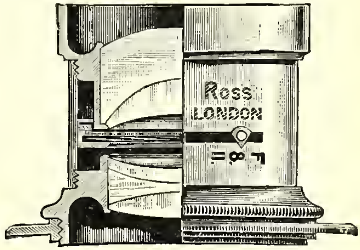


FIG. 74.—Series IIA.

balancing a positive aberration by a negative one of equal magnitude. (See Spherical Aberration.) This is done also in the case of astigmatism. Now a "new achromat"—to use again the designation of Professor Silvanus Thompson for a lens in which the positive member consists of glass of higher refraction with lower dispersion—has its cemented surface positive or converging, and therefore introduces an astigmatic aberration which is opposite to that produced by an old achromat which has its cemented surface divergent. By the combination of two lenses of these types the principle clearly set forth by Dr. P. Rudolph is realised. This principle is known as "the opposed gradation of the refractive indices." In the Rudolph anastigmats the combination of an "old" and "new" achromat enables radial astigmatism to be eliminated and at the same time a very flat field to be produced.

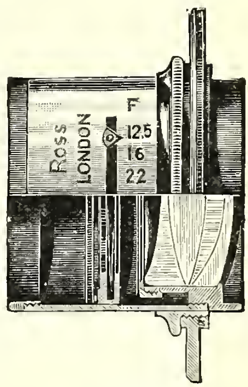


FIG. 75.

This same principle was applied by Rudolph in 1894 to the production of a single lens with an astigmatically flat field, which was brought out by Carl Zeiss under the title of Anastigmat Lens f12·5. The separate elements of this lens being cemented together may remain uncorrected so long as the whole lens is spherically and achromatically corrected. The one condition to be observed

if radial astigmatism is to be eliminated, is that the Rudolph principle of opposed gradation of the refracted indices may be realised—*i.e.* that two of the lenses form an old achromat and two a new achromat. This can be done in the case where only three lenses make up the achromat, as shown in figs. 76, 77. A lens of this type was made according to Dr. Rudolph's formulæ in 1891 by Carl Zeiss,

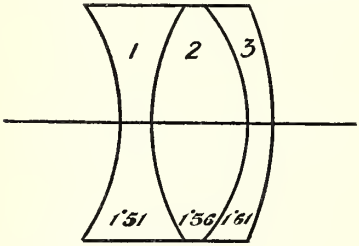


Fig. 76.

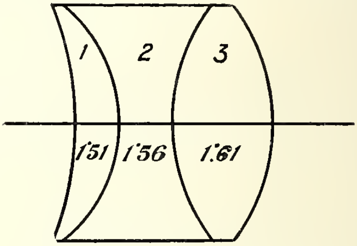


Fig. 77.

and was placed on the market by the same firm in 1893 as Satz anastigmat, Series VI.

The triple anastigmatic lens thus produced by Dr. Rudolph, in extension of his principle of opposed gradation, was independently arrived at by Von Högh, and two lenses of this type were combined to make a symmetrical double anastigmat, which is placed on the market by C. P. Goerz as the "Double Anastigmat."

The Holostigmat of W. Watson & Sons is the latest addition to the group of symmetrical anastigmats, and according to its computer, A. E. Conrady, "differs entirely from the other lenses of this group in the construction of its triple cemented back lens, which consists of a crossed convex lens cemented between a bi-concave lens and a meniscus, the least refractive glass being placed next the diaphragm and the glass of highest index outside."

A convertible "Satz" lens working at *f*6·1 has thus been produced which, while being so perfectly corrected for the usual medium angle field as to completely fulfil even the requirements of photo-micrography, becomes an excellent wide angle lens with 90° field when moderately stopped down. The single combination answers perfectly as an aplanatic or anastigmatic landscape lens working at *f*11·3.

CHAPTER VIII.

LENSES PAST AND PRESENT. PROPERTIES FROM THE USER'S POINT OF VIEW.

This Chapter is by Thomas Bolas, F.C.S., F.I.C.

[1] *The simple Uncorrected Lens, or Spectacle Lens.*—Ordinary spectacle lenses are very various in character, and by taking advantage of the forms easily obtainable, the photographer may do nearly or quite all that is required in the usual pictorial photography, assuming that extreme rapidity and minute definition all over the field are not required. Old spectacle lenses are to be found in the odd storings of most houses, and often a mixed lot of 30 or 40 may be bought for a shilling at a second-hand shop; still, when a lens of particular character and focal length is ordered, 2s. 6d. is by no means an unreasonable charge, and if the lens is made of quartz (commonly called a pebble lens) the charge may be more. In all cases where spectacle lenses are used, a correction for chromatic aberration must be made after focussing. See instructions further on.

[2] *The usual Double Convex Spectacle Lens*, if used without a diaphragm, will give fair, but not critical, definition over a very limited area, hence it may serve for rapid exposures when there is a central figure and the rest is to be indistinct. The area of moderately good definition will in this case be about 1½ or 2 ins. in diameter for a lens of 6 ins. focal length, but when lenses of longer focal length are used the diameter of the area of fair definition will increase rather more rapidly than the focal length. The extent and character of the definition can be improved by using a small stop close to the lens, either before or behind, but in this case the field will be very curved or cup-shaped. The curved field may be an advantage in a few cases (certain interiors, for example); but to flatten it and at the same time improve the definition, the stop should be in front of the lens at a distance equal to one fifth of the focal length. If a wider angle is required the stop may be nearer to the lens.

[3] *The Meniscus or Periscopic Spectacle Lens.*—This form is con-

vex on one side and concave on the other side, but the convex face has the greater curvature; and all things considered, it is the most generally useful form of spectacle lens. If used with full aperture while the convex side is outwards, or towards the scene, it gives fair definition over a small area. If, on the other hand, the meniscus lens is turned so that its concave surface is away from the plate, or towards the scene, there will be no sharp definition anywhere. The use of the diaphragm in this case is the same as before. A diaphragm close to the lens will bring up definition in the one case, and extend it on the plate from the middle outwards in the other; as before, the field will be much curved. To flatten the field the diaphragm must be set at a distance from the lens; as a matter of fact the diaphragm may be before the lens or behind it; the marginal lines of the subject will be a

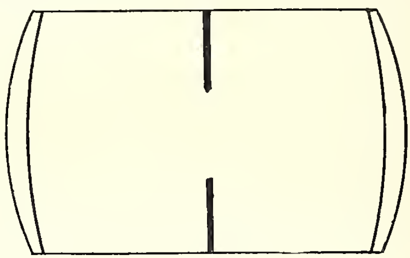


FIG. 78.

little bent outwards at the corners (pincushion distortion) when the stop is behind, and a little inwards when the stop is in front. If the focal length of the lens is considerable in relation to the size of the plate—let us say a lens of 8 ins. focal length for a quarter-plate—this distortion is of practically no importance. By using two meniscus lenses with the stop between them this distortion can be eliminated, and we get the spectacle lens rectilinear doublet, fig. 78. From what has been said it is quite evident that by using spectacle lenses in various ways considerable control over the results may be obtained. These methods of use, explained above in words, are further illustrated with diagrams in the section on the achromatised meniscus or ordinary view lens.

[4] *In using uncorrected lenses a universal rule is—In order to compensate for the chromatic aberration of the ordinary spectacle lens or its doublet, it is necessary to move the lens in or towards the plate after focussing, the amount of this movement inwards being equal to one fortieth of the focal length of the lens; and thus if the focal length is*

eight inches, it will be shifted inwards, or towards the sensitive plate, two tenths of an inch after focussing. This rule is not absolutely exact but sufficiently near in practice, especially as microscopic definition is not ordinarily sought for by workers with spectacle lenses. Still with small stops and the above correction (say *f*32 to *f*28), miscroscopic definition is obtainable with spectacle lenses. When small stops are used very special care must be taken that the edges are sharp; in other words, that the aperture is a hole like fig. 79A, and not a tunnel with reflecting sides like fig. 79B.

FIG. 79A.

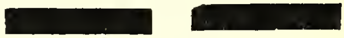


FIG. 79B.

[5] *The Achromatic Meniscus or ordinary Single View Lens.*—This is the near equivalent of the meniscus spectacle lens, but by the use of two pieces of glass (a double convex crown glass and a double concave flint glass) the lens is partially corrected for chromatic aberration. The difference between the achromatised meniscus as used for the object glass of medium quality opera and field glasses, and the actinised meniscus specially sold as a photographic view lens, is so small as to be unimportant. Still this may be said: Every achromatised meniscus as used for the object glass of a moderately good opera or field glass is well suited for photographic work, although the corresponding form, very specially and carefully adjusted for photography, will not always function well as a telescope objective. An old and damaged opera or field glass, having meniscus object glasses (not triplets), will often furnish an excellent pair of view lenses.

[6] *The Diaphragm and the View Lenses.*—Writers on photographic optics ordinarily mention only one way of using the view lens; namely, that method of using it which came into vogue in the early days of photography when equal and sharp definition all over the plate on a flat field were the ideals. This old method of setting up the view lens is far too commonly looked on as the only one, although other methods of setting up the view lens adapt it to the many needs of the pictorial photography of our day. The ordinary view lens may be looked upon as an instrument of wide powers, the most real value of which is overpowered or lost by the survival of an old method of using it—or, rather, because this one method is commonly looked on as the only method.

To the maker of pictorial photograms the old style view lens can do better service than all the high class modern lenses, although he may occasionally require the latter; but the powers of the view lens

must be understood. The conditions of use already mentioned as relating to the uncorrected or ordinary meniscus apply also in the main to the corrected meniscus or common view lens, therefore all the verbal particulars need not be repeated. Fig. 80 shows view lens mounted to give the highest rapidity, but only a small area in the centre of the field will be sharp (see above under heading Spectacle Lenses). By raising or lowering or side shifting the front of the camera, the sharp area may be brought to any part of the plate. The view lens used as shown by fig. 80 covers a very wide angle but without definition at the margin. For pictorial subjects with only one motive, or centre of interest, the view lens should generally be used as

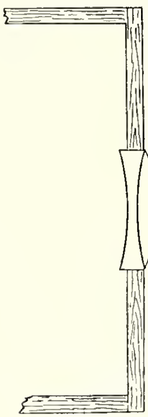


FIG. 80.

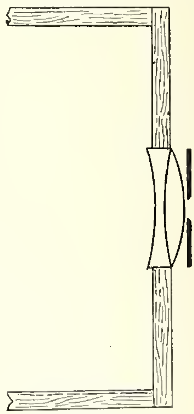


FIG. 81.

shown in fig. 80. The field in this case will be deeply curved or cup-like.

Fig. 81. Lens as in fig. 80, but a diaphragm in front, and close to the lens. The definition will be improved and the area of definition somewhat extended. The angle covered will be less than in case of fig. 80. The curvature of the field will remain nearly as before.

Fig. 82. Diaphragm removed to a distance from the lens. As the diaphragm is removed further (up to about one fifth of the focal length) the field of the lens flattens, thus gradually fitting the lens more especially for an ordinary scene all parts of which are at about an equal distance from the lens. The definition improves and extends as the stop is smaller, but the definition on the axis will always be better than at the margin. By varying the size and distance of the stop and shifting the axis of the lens by a movable front, almost any required

localisation of definition can be obtained. Marginal distortion of the straight lines (barrel-like in this case) will not be very noticeable when a lens of long focus (say 9 ins. focal length for a 5 × 4 plate) is employed.

Flare may disturb in some cases, and may be an advantage or a trouble. See section on Flare.

Fig. 83. As fig. 82, but with stop inside. Either close as B, or at a distance of about one fifth of focal length, A. The general conditions are as in figs. 81 and 82, but the distortion of marginal lines will be of the pincushion kind; flare may step in, and occasionally a parasol or hood to the lens may be required. If it is desired to increase the sharpness without destroying the curvature of the field

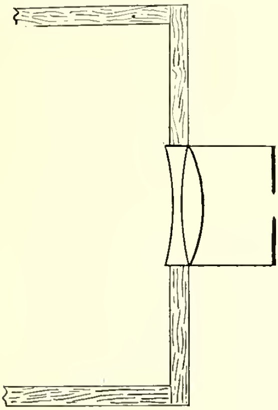


FIG. 82.

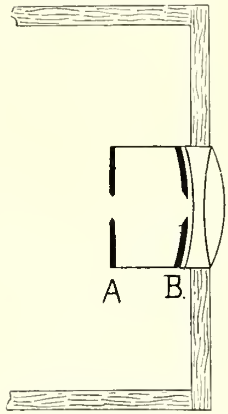


FIG. 83.

the diaphragm should be close to the lens as at B; the cup shaped diaphragm plate makes this possible. Curvature of field, besides the use mentioned above, is often a useful aid in localising sharpness. To take full advantage of curvature of field in this respect the principal object should be on the axis of the lens, but not necessarily in the middle of the plate, as the camera front can be shifted, and the subsidiary objects should rather be grouped behind than before the principal object.

Fig. 84. Definition very confused all over the field. Field much curved. Angle wide.

Fig. 85. A diaphragm close to the lens improves definition but leaves the field curved. For obtaining local definition in a case like this, see No. 83, where curvature of field is utilised.

Fig. 86. To flatten the curved field of fig. 85 more or less, remove the diaphragm away from the lens, the most considerable effect being at a distance of about one fifth of the focal length. This arrange-

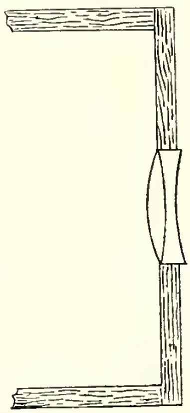


FIG. 84.

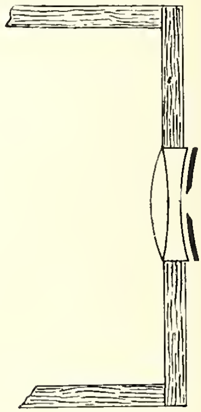


FIG. 85.

ment, and with the diaphragm at a distance from the lens, has generally been regarded as the only one suited to photographic work, and view lenses as sent out by the opticians are ordinarily mounted for being

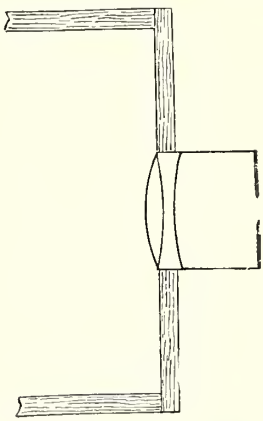


FIG. 86.

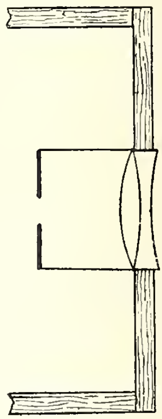


FIG. 87.

used as shown by fig. 86. We have in this notion a survival of ideas from the time when flatness of field and uniformly fine definition were considered to be essentials in all cases. The diaphragm in this

instance flattens the field and sharpens the image in approximately equal steps. When the diaphragm has an aperture of from *f*16 to *f*32 the definition is very good. There is barrel-like distortion, but it is not very noticeable unless the focal length of the lens is rather short in relation to the size of the plate. For ordinary landscape subjects the distortion is negligible.

Fig. 87. As fig. 86, but diaphragm is behind the lens. All conditions are substantially as in case of fig. 86, but such distortion as there is will be of the pincushion kind.

Fig. 88. A combination of two similar achromatised landscape lenses, with the diaphragm between them. Such a combination is rectilinear, that is to say, does not deform the marginal lines, so can be used for copying. The definition is nowhere critical with full aperture, although best in the centre of the field or on the axis of the lens. The want of defining power is due to spherical aberration, and

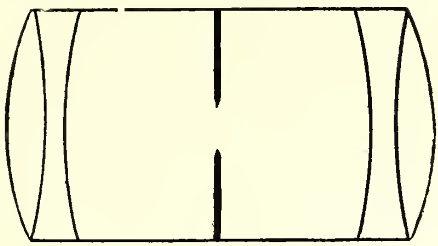


Fig. 88.

spherical aberration may be reduced to any required extent by the use of a small diaphragm. A position or degree of separation may be found by trial at which the field is practically flat, but in this case astigmatism will much injure the marginal definition. Still in all cases astigmatism will limit the use of such doublets to moderate angles when fine marginal definition is required. By bringing the lenses closer together a wider angle will be included, but the marginal definition will be increasedly faulty by reason of astigmatism, and the field will ordinarily be much curved.

Dissimilar lenses of the achromatised meniscus type may be combined into doublets with very good effect, and then the diaphragm should be placed not midway but at a distance proportional to the focal lengths of the two lenses. The photographer who works for pictorial effect only, need seldom or never go beyond the ordinary achromatised view lens either singly or in combination, and anyone who is mechanic enough to construct suitable mounts may at a small

cost furnish himself with a useful battery of elements for combination. Further, it is often an excellent plan to combine an uncorrected spectacle lens with an achromatised lens. The wide latitude as regards centring is quite surprising; this latitude as regards bad centring only exists in the case of elements each of which is complete in itself: thus, for example, there must be no fault in the centring of the front and back of a portrait lens, as the back is mainly a corrector for the front.

[7] *Wide Angle with ordinary View Lenses, and their Combinations.*—The ordinary view lens, whether as a single lens or as a doublet, is best adapted for narrow angle work, and the pictorial photographer does most of his work so as to include a narrow angle, say 45° or less. When, however, the pictorial exigencies demand a small area of sharp or moderately sharp definition, with the margins of the sheet indistinct (an effect most easily produced by means of the ordinary view lens as explained above), it is sometimes desirable to so use the view lens as to include a wide angle. Used as shown by fig. 80 (*i.e.* convex side towards object, no stop and no tube), the view lens will ordinarily cover a field of from 90° to 100°, but light and definition will fall off towards the edge. If the lenses of the doublet (fig. 88) are brought very close together, an angle of 90° may usually be included, and by the use of a small stop good definition may be obtained over about 60°. If there is a choice, view lenses with the concave rather deep should be selected for wide angle work. Occasionally view lenses and opera glass lenses are made with the concave very shallow; while sometimes there is a flat instead of a concave. Such lenses are specially suited for narrow angle work.

When a wide angle is to be included with critical definition to the edges, the modern highly elaborated and expensive lenses are an essential. The wide angle photogram with critical definition to the edges is a technical rather than an artistic necessity.

[8] *Difference between Actinic and Visual Foci as affecting the ordinary View Lens.*—In the above considerations regarding ordinary view lenses no distinction has been made between lenses which are achromatised for visual effect (such as opera glass lenses) and those which are achromatised for actinic effect. There is no practical necessity to make any such distinction, as the highest or most critical definition depends on the use of a small stop, and the small stop gives so much depth of focus as to make the slight difference between the two achromatisms a matter of no practical importance. The case is otherwise with rapid or aplanatic landscape lenses which will give

sharp definition with a large aperture. With these lenses a special actinic correction is desirable, but with the modern large aperture or wide angle doublets a much higher chromatic correction is required—the so-called apochromatic correction by which several points in the spectrum are brought into coincidence.

[9] *Highly corrected View Lenses and their combinations into Rectilinear Doublets. Anastigmats.*—The want of defining power of the ordinary view lens used in the old fashioned way (fig. 86) is chiefly due to spherical aberration, at any rate as far as the axial rays are concerned, and the only way to so reduce this spherical aberration as to obtain general sharpness is to use a small stop. The desire for sharpness combined with rapidity led to many improvements in the view lens, and in the doublets formed by their combination. These improvements were at first directed towards the elimination of spherical aberration and afterwards to the correction of astigmatism and the aberrations of the oblique pencils. Finally a higher chromatic correction was introduced (apochromatic correction), and we now have view lenses of altogether surprising perfection : instruments of special value for instantaneous street work, photographing buildings when in confined situations, also for copying, more especially when it is desirable to work at short range, often a matter of considerable importance to process workers in cities.

The chief of the various view lenses are described below. All may be used as doublets (two being mounted as shown in fig. 88), but in some cases this does not appear to have been done ; while in the case of such a lens as Dallmeyer's rectilinear landscape lens (fig. 22), there is no particular reason for employing two together in the form of a doublet. Others, like the globe lens (fig. 21), and some other special wide angle forms, have almost always been used in the doublet form, as when used singly distortion may be too considerable a factor.

Speaking very generally, all the lenses described as highly corrected view lenses have chief properties more or less similar to those of the ordinary view lens. They may be used in all the ways already indicated ; but when those well marked protean effects which are above described are required, the old and cheap form is to be preferred. All these lenses will combine fairly well to form doublets if mounted as fig. 88, so that the distortion of the two elements is opposite in its nature. The distortion of the two parts will not always be equal, therefore the combination will not always be quite rectilinear. As Dallmeyer's rectilinear landscape has in itself no element of distortion,

it is obvious that it should not be combined with another landscape lens in order to secure a mutual correction.

Fig. 89 is a view lens made by Andrew Ross in 1841. The positions of the crown glass and flint glass are in a sense reversed, as the convex exterior is of flint glass, and the plano-convex is of crown. It was used as a single view lens with the flat face towards the scene and a diaphragm in front. An ordinary landscape lens was sometimes added to convert this lens into a doublet. This early lens is interesting as being a first step towards those changes which led to the popular rapid symmetrical.

Fig. 90. Grubb's aplanatic, 1857. The same idea more fully carried out. The glass having an external convex face is flint, and

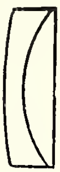


Fig. 89.

Fig. 90.

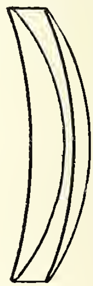


Fig. 91.

that having an external concave face is crown. Used in the "ordinary" way of a landscape lens (as fig. 86) this lens gives good definition for views with an aperture of *f* 8 to *f* 12. The Grubb aplanatic lens was mostly sold as a single lens, but doublets (mounted like fig. 88) are occasionally met with. All of these lenses which I have tried are fully equal to the best of the later rapid symmetricals or rapid rectilinears. To Grubb must be given the chief credit for this kind of lens.

Fig. 91. Dallmeyer's wide angle landscape lens, 1865, an improvement on the Grubb lens, whereby astigmatism is reduced. The negative glass of soft flint is sandwiched between two crown glass positives, and by using two kinds of crown glass an additional means of correction is provided. A modification of this lens is the rapid landscape lens of the second Dallmeyer (1884), whereby spherical aberration was much reduced and larger apertures could be used for moderate angles.

Fig. 92. Steinheil's aplanat, 1866. Practically the Grubb aplan-

atic lens of 1857. Sold mostly as a doublet. This lens has been made with more or less modification by most opticians and sold as a rapid doublet ($f6$ to $f8$) under various names, such as symmetrical, rectilinear, etc. To Steinheil, Dallmeyer, and the Ross firm belongs the chief credit of having popularised this form, the most esteemed lens for general outdoor work between 1870 and 1890, and since then it has been the staple lens for those not caring to go to the expense of the best anastigmats. The newer kinds of glass give additional scope in correction, and sometimes these doublets have been made with four kinds of glass. Still all lenses of this class work well or fairly well as single lenses.

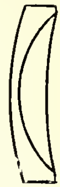


FIG. 92.

[10] *Purchasing and selecting the Rapid Symmetrical Lens.*—The importance of the rapid symmetrical lens justifies a short section on its economics and use. The equivalent focal length of a rapid symmetrical for general use should be about $1\frac{1}{3}$ the longer dimensions of the plate: thus for a whole plate ($8\frac{1}{2} \times 6\frac{1}{2}$) the lens should have a focal length of a little over 11 ins. The largest stop will usually be about $f7$ or $f8$, and with the full aperture reasonably good photograms of instantaneous street scenes should be obtainable on plates of the size mentioned, and this in spite of the fact that a fine cross near the end of the plate will not be rendered, and that a critical examination will certainly show default of sharp detail somewhere. Ordinary landscapes and sea views can be taken with full aperture (on a plate the long side of which is about two-thirds the focal length). Under these circumstances there is no important falling off of the illumination towards the margin of plate when the rapid symmetrical is so mounted that a next larger plate is covered without any part being obscured by the circle of shadow. It will generally cover the next larger plate if a small stop (say $f32$) is used, but the margin will not be well illuminated, and anything like critical definition at the edges will be out of the question.

[11] *The cost of rapid symmetrical or rectilinear* lenses of the same general construction varies much, as in the making of this particular form some of the more cutting opticians have come up nearly level with the old established firms of high repute. Thus the whole plate lens ($f7$ or $f8$, and about 11-inch focal length) is about £6 6s. in the lists of the first class opticians; but most dealers will supply French, American or German lenses of really good quality for half the money, and sometimes for considerably less than half. Any one who is allowed by his dealer to test a few lenses from the stock

of lower priced symmetricals can often, indeed generally, save half his money; still he has to work to effect this saving, and many persons will prefer to take the wares of the high class optician and consider that one half of the price is for the lens itself, and the other half for an absolute guarantee of first class excellence.

[12] *Tests which an 11-inch Rapid Symmetrical should pass.*—A leader column of *The Times* is set up on a well lighted wall and things are so adjusted as to reduce the column on the ground glass to half an inch wide. Assuming the glass of the focussing screen to be fine and an eye-piece to be used, the type should be quite easily legible in the middle of the field, the lens not being stopped down. To test for marginal aberrations, let the slip of *Times* leader be extended by joining two pieces so that the half-inch-wide image divides the plate lengthwise. The middle being focussed sharply always with the full aperture, it will be found that the lettering at the ends of the plate is out of focus, and to bring the lettering at the ends of the plate into the best focus the back of the camera will generally have to be shifted forward, showing that the field is concave. The racking, owing to the concavity of the field, should never be more than *three-quarters of an inch.* Generally it will be much less. On the column matter near one end make a bold cross with ink, the lines being half an inch long and $\frac{1}{32}$ of an inch wide. The image of this cross should come at one end of the plate, one line being parallel to the end and the other at right angles to the end of the plate, and this latter line should point towards the centre of the field. First focus one line of the cross and note the shift of the back required to bring the other line of the cross into focus. This shift (call it "astigmatic difference") should not be more than five-eighths of an inch.

Such extremes of curvature in the field, on the one hand, and of astigmatic difference, on the other hand, should not coexist in the same instrument. The two are to a large extent exchangeable. If there is much astigmatism we may partly exchange it for curvature of field by bringing the two elements of the doublet a little nearer together. If, on the other hand, the field is much curved, we may lessen the curvature by separating the elements of the doublet, but this will increase the astigmatism.

Test for achromatism (or actinism). This is very necessary, especially as unachromatised symmetricals are sometimes sold. First see that the focussing screen of the camera and the face of the plate in the slide come to the same position. This is best done by focussing

a part of a line subject sharply with a rapid lens first on a piece of ground glass fitted in the dark slide, and then on the focussing screen. If there is a difference, one or the other must be adjusted. Practically, very few commercial cameras with many slides or sheaths are in good focal adjustment.

The long slip of *Times* leader being in position as in the last mentioned test (for astigmatism), focus sharply (with full aperture of lens) on a line which comes about half way between the middle and the end of the plate. Expose a plate and develop. If any line of the printing is sharper than that which was focussed, the achromatism or actinism of the lens is faulty. Rapid rectilinears of shorter or longer focal length should define similarly, and the maximum fault allowable from curvature of field and astigmatic difference should be proportional to the focal length, in the ratio given above for an 11 inch lens.

[13] *Lenses for extremely wide angle.*—Fig. 93. Busch's Pantoscope (apparently made as early as 1865), is at the present moment the prince of lenses for quite exceptionally wide angle. The construction is more analogous to the old view lens than to the aplanatic lens of Grubb, but the periscopic principle is carried to extreme. This lens is a triumph rather of skilful construction than of optical innovation, the construction of the deep or thin inner flint glass being a very delicate operation. The pantoscope is always sent out and used as a doublet, and as it must be employed with a small stop its spherical aberration is of no importance. The most real use of the pantoscope to the photographer is for photographing buildings in close situations when records are wanted for trade or other purposes. As sent out, the pantoscope will include an angle of 110°, but if the user cares to construct a somewhat shorter tube the angle included may be increased to 120°: thus a pantoscope of $4\frac{3}{4}$ ins. focal length will not only cover a 12×10 plate, but a little margin will be left for raising the front of the camera.

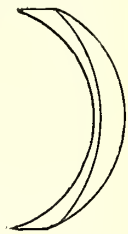


FIG. 93.

[14] *Using a lens of extremely wide angle.*—A photographer who imagines that he can obtain the best results over an angle of 120° by merely screwing the lens on an ordinary camera and going ahead in the ordinary way makes a great mistake; even if the construction of the camera allows a clear range inside and out for a cone of 120° the resulting picture would be much under-exposed at the margin, as the light necessarily falls off much towards the edges. The following are the chief needs. (1.) The stop must be small, $f64$ at the most.

(2.) Some kind of light equaliser must be used; the most convenient being a starfish-shaped piece of black cardboard (fig. 103), which is made to rotate in front of and near to the plate during part of the exposure (ordinarily during half or two-thirds of the exposure). The star should be made unsymmetrically as shown, and if supported as indicated the whole can be drawn down into a well attached to the camera when not in use. Slow rotation is sufficient, provided that the star is kept in motion; two threads, each wound right and left handed on a small rounce, being used to keep the star in motion, the thread passing through the outer casing. The shading from the supports will be very trifling if they are thin; and as this shading affects the sky chiefly, retouching is easy. (3.) The glass of the plate should be

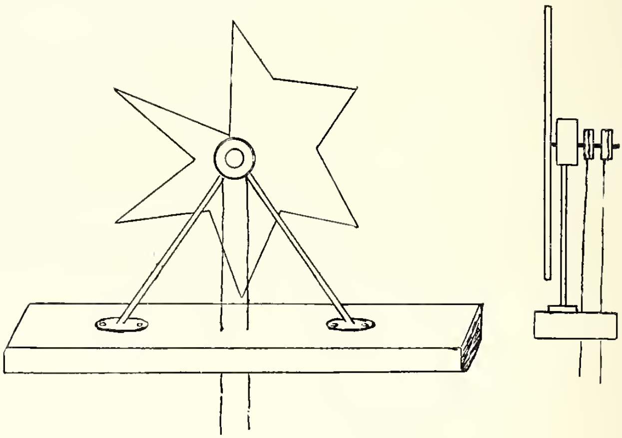


Fig. 103.

flat, as when the incidence is very oblique a slightly irregular surface may tell. (4.) The camera and stand must be very firm and solid, otherwise the manipulation of the star screen and the break in the exposure might cause a general unsharpness. Obviously it would be unreasonable to expect very critical sharpness as far as the margin is concerned. Dr. Meydenbauer asserts that when a pantoscope is used for an angle of 110° the illumination at the margin is only one sixth of that at the centre, and he further states that if diluted rodinal is employed as a developer the effect of this falling off of the light will be minimised.

Fig. 94. The Ross portable Symmetrical or wide angle Symmetrical, always sold as a doublet. A construction similar to the last but not so deep. Will cover 90° with a small stop.

Fig. 95. Globe lens. Sold as a doublet. A somewhat similar lens for about 100°.

Fig. 96. The Ross Concentric. Sold as a doublet. The plano-convex is formed of glass having high refractive but low dispersive

Fig. 94.

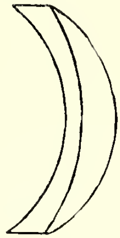


Fig. 95.

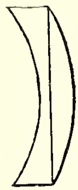


Fig. 96.

power, achromatised by a plano-concave of high dispersive power. At *f* 20 it gives fine definition, and this definition is critical even to the margin of the plate. This, together with evenness of the illumination and flatness of field, makes this lens a valuable instrument for copying when rapidity is not essential.

Fig. 97. Dallmeyer's Rectilinear Landscape lens. This stands quite by itself, as a landscape lens which does not distort. It is about as aplanatic as the Grubb aplanatic lens (fig. 90) and the

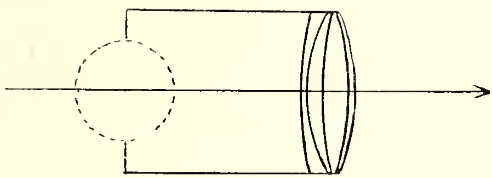


Fig. 97.

astigmatic correction is better, therefore it can be used for copying plans, or for process work. Angle medium (about 60) illumination very equal.

The Modern Anastigmat.

[15] The first lens in which both spherical aberration and astigmatism were eliminated with a flat field, is Piazzi Smyth's combination of a Petzval portrait lens (fig. 104, A) with a plano-concave close to the plate (fig. 104, B), this form dating back to 1875. It is specially valuable for lantern work, and is manufactured by Swift of Tottenham

Court Road, London. Soon after this Dr. Schroeder constructed highly complex objectives in which many glasses allowed the high correction of the various aberrations, but he appears to have looked upon such constructions as too complex for the market. As new qualities of glass became available, and with the advance of optical enterprise, novel and complex forms came on the market, a triplet of Rudolph and a doublet due to Hoegh and Goerz leading in 1892 and 1893.

The modern highly complex lenses involve new systems of working in the optical factories; the final figuring being done on the polished glasses by trial with a standard reverse, or glass mould, used after the manner of a surface plate, but the indication of contact is afforded by the observation of the Newton's rings, or the interference colors of the thin plates of air.

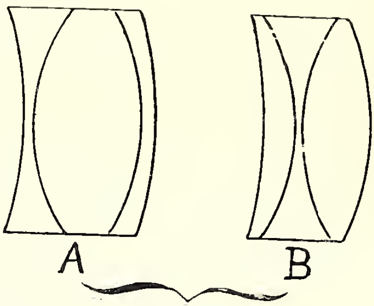


Fig. 98.

It was thought at first that the increase in the number of glasses in the modern anastigmat would balance all optical gains; but this has not proved to be the case, owing to the introduction of better work in surfacing. Still the modern highly complex lenses have not yet reached the stage of cheapness, and it is difficult to see how high class figuring by the new methods can ever be cheap. It is impracticable to describe all the various forms of modern anastigmatic lenses. Very approximately, the competition is such that the real value is about proportionate to the price.

Fig. 98. The Goerz-Hoegh anastigmat—in two forms, A and B, the latter being that preferred by Dr. Goerz and now sold—is supplied both as a single lens and as a doublet. The doublet is now sent out to work at $f6{\cdot}8$. Usual angle included is = 70°, or with small stop 90°. Field flat, and illumination very equal.

Figs. 99 and 100. Anastigmats, 1893 to 1895, used both as single lenses and as doublets.

Fig. 101. Steinheil's orthostigmat, 1896. As doublet or as single lens.

Fig. 102. The universal form of Dallmeyer stigmatic. It consists of two elements, each an excellent landscape lens, although they are different in their construction. The back combination has a focal length of about one and a half times that of the complete doublet, while the front combination has a focal length of about twice that of

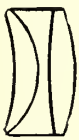


Fig. 99.

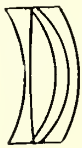


Fig. 100.

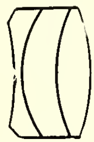


Fig. 101.

the complete doublet. This lens works at $f6$ and the size which is best adapted for general work on a plate $8\frac{1}{2} \times 6\frac{1}{2}$ (10·7 ins. focal length) will cover a 15×12 plate if a stop of $f16$ is used, and this with fairly equal illumination.

The number of anastigmatic doublets capable of division into two good landscape lenses is now so great that even the names cannot be mentioned. The above are, however, representative examples.

[16] *The pass test for an Anastigmatic or Stigmatic Doublet.*—The long column of *Times* leader having been set up as already directed

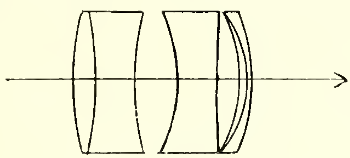


Fig. 102.

and to the same standard of reduction (p. 84), it should be possible to find a focal plane in which the whole is distinctly legible at the same time, the full aperture of the lens being used. If the lens has a greater rapidity than $f6$ a little leniency may be allowed. For the whole-plate lens (about 11 ins. focal length) the racking in for curvature of the field should not exceed one tenth of an inch, and the astigmatic difference should not be more than one twentieth of an inch, the test being made as on the margin of a whole plate, as directed (p. 84) for the case of a rapid symmetrical. In

the case of lenses of longer or shorter focal length proportionate errors may be allowed. The test for achromatism is made as already directed in the case of the symmetrical. The anastigmat should pass the test absolutely, but care must be taken not to misjudge by reason of want of register between dark slide and focussing frame. A very firm and well made camera is required for this test.

[17] *Combining Lenses : further Notes.*—The lenses described above may be combined to form doublets, and when sold as doublets each part may be used as a complete landscape lens. Further, they may be intercombined in any way; fig. 88, and the instructions given in connection with it, being the basis, but the corrections for distortion, flatness of field, and astigmatism will often be more or less stultified by combination. In other words, the most critical performance must not always be expected; still combination is very useful in many cases. As already explained, very bad centring will do in the case of the less perfectly corrected lenses, but in the case of the anastigmats fairly good centring is required; in other words, an extemporised pasteboard tube is not good enough for those who are critical in their requirements. An optical mounter or jobbing mechanic will often make special brass tubes at a low cost and make them so well that the combined lenses scarcely suffer. See also p. 96.

[18] *Flare is a trouble* that besets the combiner of lenses, when subjects with great contrasts are photographed. It sometimes shows itself as a whitish or light glare on a portion of the subject; sometimes as a ghostly image of a chief light, as for example an east window in a church. In these cases it is due to reflection from certain surfaces of the lens. While looking at the picture on the focussing screen slightly shift the diaphragm or alter the distance of the lenses. The condition under which the flare spreads itself harmlessly over the field will then be found. Care must be taken that there are no bright or semi-bright places inside the mounting tube. When the thick edge of a lens is semi-polished, reflection may take place from it. The remedy is to black-varnish the edge.

Various Special Lenses.

The lenses which are next to be considered are special constructions in a more complete sense, as they will not separate into two complete and satisfactory lenses, as is the case with ordinary rectilinear or anastigmatic doublets.

19] *The Portrait Lens or Petzval Doublet.*—This notable lens, which

was quite an innovation, is shown in section by fig. 104, A. The front combination is an ordinary view lens with the convex surface outwards, while the back combination consists of an outside crossed lens of crown glass and an inner concave convex of flint glass. The back combination is a correcting lens merely, and is not suitable for separate use. The most remarkable quality of the portrait lens is perfect correction of spherical aberration for the middle of the field, even when the aperture is as large as $f3$; moreover, if the lens is well constructed no other aberrations affect the middle of the field. Hence it is that by using a portrait lens it is possible to obtain microscopic definition over a limited area, and this together with

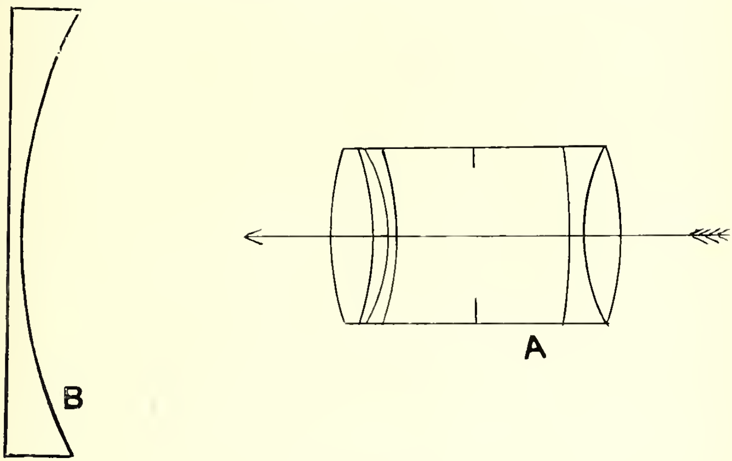


FIG. 104. A, B.

extreme rapidity; hence no lens is more suitable than a good portrait lens for stellar photography.

Although the various anastigmatic doublets are invaluable when fine definition is required all over a large field, they cannot, as a rule, equal the exquisite definition which a first class portrait lens will give over a small area.

Considering all things, no lens is so suited as the portrait lens for single figures or groups of two or three in the photographer's studio, but English portrait photographers ordinarily use portrait lenses of an undesirably short focal length (this being owing to the shortness of the studio). A huge portrait lens with glasses of 6 ins. in diameter, and having a focal length of about 28 ins., may often be used with advantage for the smallest portraits: and a useful method

of using the portrait lens, when we want rather less sharpness, but sharpness spread over a larger area, is shown by fig. 104, D.

The portrait lens may generally be adjusted so that almost any compromise can be effected between a round field and bad marginal definition by reason of astigmatism. Considerable separation of the front and back combination gives a flat field and much astigmatism, while a shorter tube will give no astigmatism but a curved field. The curvature of field may be remedied by a large plano-concave lens set immediately before the sensitive plate (fig. 104, B), a device due to Piazzi Smyth; a portrait lens thus fitted and adjusted being substantially corrected on all points.

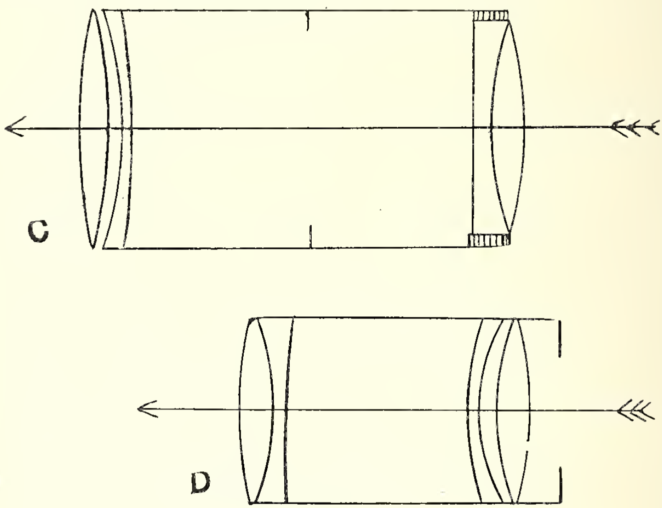


Fig. 104. C, D.

[20] *Dallmeyer form of the Petzval Portrait Lens.*—In this the positions of the elements of the back combination are reversed (fig. 106) and otherwise modified. This form is decidedly an improvement on the original, and it is now adopted by all the best Continental makers. By increasing the distance between the elements of the back combination, any desired amount of spherical aberration may be introduced; this being a convenient method of introducing a carefully regulated amount of softness. Some of Dallmeyer's lenses are fitted with a screw device for the above purpose. (See p. 128.)

Fig. 104, D, shows a method of using the portrait lens by which a very little diffusion of focus is introduced, but with the advantage of

a corresponding gain in definition and lighting away from the centre: an arrangement well suited for groups in the studio. The lens is reversed and the diaphragm is in front of the reversed lens as shown.

[21] *The Dallmeyer f4 Stigmatic Portrait Lens.*—This lens (fig. 105) (not to be confounded with the separable stigmatic mentioned above) is a construction which, like the Petzval lens, gives microscopic definition, and it is as suitable as is a Petzval lens for photographing the fainter stars and the solar streamers. In addition, it gives fine

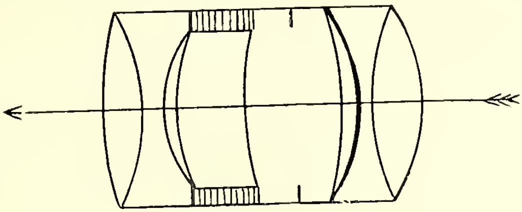


FIG. 105.

definition over a large flat field; the angle included being about 60°. This lens is not separable into two working lenses. Although less suitable for some classes of studio work than is the form last mentioned, the *f*4 stigmatic represents the climax of up-to-date perfection for group work, or whenever fine definition is required all over the plate, together with extreme rapidity.

[22] *The Telephoto Lens* is a recent introduction of Mr. Dallmeyer, and is based on the principle of some old devices of the nature of

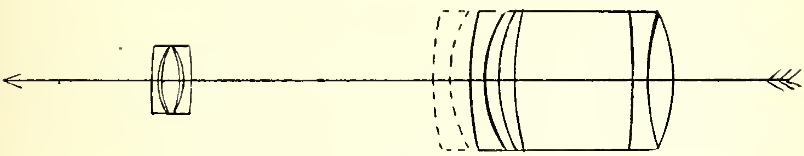


FIG. 106.

the Barlow lens. A negative combination of somewhat higher power than the positive is placed behind the positive lens, whereby the rays impinge on the plate as if they were projected by a lens of longer focal length, thus giving a larger image for a determinate camera extension. The special value of the telephoto lens rests in its power of giving large images of distant objects, and fig. 106 shows one of many possible forms, as any ordinary photographic lens may have a negative back-glass adapted to it. Fig. 106 shows Mr. Dallmeyer's

form of the Petzval portrait lens combined with a negative rapid rectilinear lens. It is desirable to have the shifting-back element to the portrait lens as already mentioned, this allowing of the introduction of just so much positive spherical aberration as shall exactly balance any negative spherical aberration of the additional combination.

[23] *The Cooke Lens.*—Fig. 107 shows a remarkable lens of comparatively simple construction, manufactured under the above name by Messrs. Taylor, Taylor & Hobson. It may be looked on as a simplified and improved outcome of a kind of lens which has undergone several modifications, as, for example, Goddard's unsymmetrical triplet (*Photographic Journal*, March 15th, 1864, p. 10), a lens by Furnell (*British Journal*, 1884, p. 238), and several lenses by Mr. H. Dennis Taylor. The Cooke lens as now made is very popular for hand camera purposes and general view work. Its full aperture is $f 6{\cdot}5$ (another series work at $f 8$), and the correction for astigmatism is

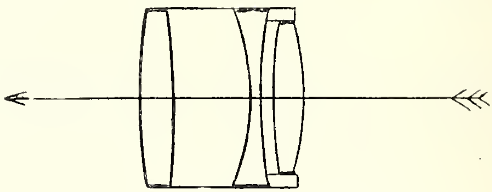


Fig. 107.

good. The instrument in question does not give two working lenses when separated.

[24] *Lenses which will not separate.*—There are many modern lenses that may be called doublets and are corrected for astigmatism, but as the front and back are not individually and separately corrected, the one lens will not make two good instruments when separated into two. It is impracticable to give a list of such lenses or a rule for distinguishing them in all cases, but a trial of the two components on the camera will soon show whether each individual element will give a satisfactory image. Often, but not always, any considerable difference in the make or style (as distinguished from size) will indicate the lens which will not separate with advantage.

[25] *The Hypergon of Goerz* is a doublet lens of recent introduction which appears to include a somewhat wider angle than the pantoscope, the range being up to 135° or 140°. I have not met with any detailed description. See fig. 103 and description (p. 86) in relation to the use of very wide angle lenses.

[26] *The Extra Rapid Lens of Dr. Grün.*—Extra rapid portrait lenses (Petzval type) have been produced but seldom used; the most rapid, as far as I know, being $f\,1$ by Mr. T. R. Dallmeyer. Such lenses have very limited use for ordinary photographic purposes, as the depth of focus is necessarily very small. Recently Dr. Grün has constructed, adapted, or altered the portrait lens, by the old Goethe-Blair system of using liquid elements in the lens. In this way a rapidity as great as $f\,\frac{1}{4}$ seems to have been realised, but no full details of the lenses have been published. Some illustrations of work with Dr. Grün's lenses appear in *The Photogram* for September 1901, p. 261.

[27] *Second-hand Lenses.*—Considering the very delicate character of high-class photographic lenses, I am inclined to think that second-hand prices rule too high. A second-hand lens may be damaged in many ways; the mount may have been slightly distorted so as to strain one of the glasses or put it in such bend that the extreme sharpness of definition will be lost; screws may be partially stripped or so damaged that it is difficult to find the starting point, and the fine polish of the glass itself may be gone. No high class lens should be bought second-hand without a critical examination or trial; unless indeed the purchaser considers that he will be content with second-class performance. Ordinary old style view lenses, and even rapid rectilinears by good makers, if faultless in general appearance, may be worth buying if the price is low; but second-hand anastigmats or portrait lenses should only be bought after very careful consideration, and if absolutely no fault can be found they may be worth about half the original price; that is to say, if they are of the kind most wanted by the purchaser. Half the price for the lens, and half the price for the direct guarantee of the maker being a reasonable apportionment. One accustomed to lenses may often judge of the defining power, condition, and other qualities by holding the lens up in front of him and examining the aerial image with a pocket magnifier. Old orthoscopic lenses by Voigtländer, orthographic lenses by Ross, and triplets by Dallmeyer, may be worth buying if offered for a trifle. Portrait lenses of high class makers and over 8 ins. in focal length will generally command a fair price. If a trial is allowed and the lens which is offered is faultless and suits exactly, it may be worth while to give one third to half the original cost; but smaller portrait lenses by good makers can often be had from 10s. to 20s. each.

As a rule it is cheaper and more satisfactory to buy exactly the lens which is required, new from the optician, than to obtain a large number of unsuitable lenses second-hand.

CHAPTER IX.

COMBINING LENSES. "MAGNIFIERS."

[1] *Altering Focal Length.*—By combining a single or double with a positive lens (*i.e.* one thicker at the centre than at the edges) the focal length is lessened; by combining with a negative lens (*i.e.* one thinner at the centre than at the edges) it is increased. It is often useful to alter the focus of one's lens in this way. One special application is in enabling the lens of a fixed-focus hand camera to be used for objects close to, as with the so-called "magnifier" fitted to the Frena and other cameras.

[2] *The Rule for Combining.*—The amount of alteration resulting from the addition of another lens follows a given rule, which is as follows:—To find the focal length of two lenses separated by a short distance, multiply the foci together and divide the product by the focal lengths added together less the distance between the lenses.

Thus in the case of two lenses 6 and 10 ins. focus and 2 ins. apart the focal length of the whole combination would be:—

$$\frac{6 \times 10}{6 + 10 - 2} = \frac{60}{14} = 4\tfrac{2}{7}.$$

If one of the lenses is negative, the calculation must be made with the focal length of this lens as a *minus* quantity. Thus if the 10-inch lens in the above calculation had been the negative the result would have been as follows:—

$$\frac{6 \times -10}{6 - 10 - 2} = \frac{-60}{-6} = 10.$$

If again the 6-inch lens had been negative, the whole combination would have had a negative focus. Thus:—

$$\frac{-6 \times 10}{-6 \times 10 - 2} = \frac{-60}{2} = 30.$$

Generally, however, one wants to work out these calculations rather differently, viz., to find what focal length of lens is necessary to alter the focus of a given lens to a given extent.

In this case the rule is:—Multiply the focus of the lens to be altered by the focus desired and divide the product by the original focus less the focus desired.

Thus: What focus lens is necessary to reduce a 10-inch lens to 6 ins. in focus?

$$\frac{10 \times 6}{10 - 6} = \frac{60}{4} = 15.$$

This is not quite accurate, because it neglects the separation between the lenses. In the above case the correct formula would be—

$$\frac{10 \times 6 - 6 \times \text{distance of separation}}{10 - 6}.$$

In the case of a landscape lens this difference can be neglected; in the case of a doublet lens the added lens is fitted between the two component lenses. According to C. Welborne Piper it is safe to take its separation as equal to half the extreme length of the doublet, when the two combinations of the doublet are of equal length.

The best form of extra lens for use within a doublet is a double convex or concave, and, like other supplementary lenses, it should be thin, otherwise the optical properties of the original lens will be upset.

The question which troubles many is from what points the distance between the lenses must be reckoned. In accurate work the distance of separation must be calculated from the node of emission of the lens nearest the light to the node of admission of the extra lens, or *vice versa* if the extra lens is placed in front. Nodal points are treated in [4], Chapter II. and Chapter XVII., from which it will be seen that the nodes of a single meniscus lens are close together slightly behind the lens; those of a symmetrical doublet fairly close together near the diaphragm; those of a periscopic doublet some distance in front of the lens.

How to find the position of these nodal points is described in Chapter XVII.

[3] "*Magnifiers*," mentioned above, are wrongly named. They do not give a magnified image of the object: they merely shorten the focal length of the lens so that with the same distance between the latter and the plate, objects quite close to the camera will be rendered sharply. The rule for finding the focal length of the extra lens for fitting in front of the ordinary lens, focussed on an infinity, is very simple. It is:—To bring close objects into focus, *fix before the lens a thin lens of focal length equal to the distance of the object.* Thus for objects 2 ft. away a lens of 24 ins. focal length. This rule can be worked out from the formula given above.

CHAPTER X.

THE TELEPHOTO LENS.

[1] *What the Telephoto does.*—In Chapter XII. it is shown that focal length determines the size of the image of any object. Large image—long focus lens, and therefore long camera extension. The telephoto lens supplies the way out of the difficulty of very great camera extensions. With it distant objects can be photographed on a scale which, with an ordinary lens, would require a bellows several feet in length. Its advantage is felt not alone in photographing distant objects. In making large copies of small and close objects it

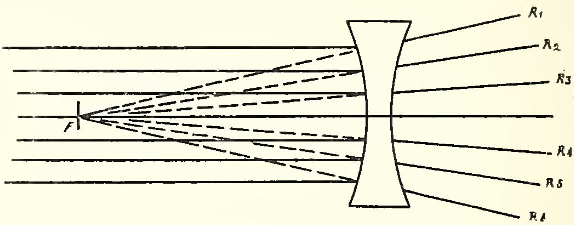


Fig. 107a.

gives the operator the great advantage of taking a more distant point of view, thus getting better perspective rendering. Technically the telephoto lens is an objective whose equivalent focal length is very much greater than its back focal length. A reference to these terms in Chapter II. will fill out this definition. Here, however, is a brief explanation for the beginner.

[2] *Principle.*—A negative lens, we know, makes parallel rays of light divergent (fig. 107a). In other words, the rays R_1 R_2 R_3 R_4 proceed on their way through the lens as though they had come from the point F, which is the focus of the negative lens. The eye placed at this point perceives a "virtual" image, but such an image cannot be received on a surface.

Now if a converging beam of light falls on a negative lens one of three things may happen according to the power of the lens. (1) The beam may be rendered divergent; (2) it may emerge as parallel light; or (3) it may pass on as a less convergent beam. This third event is shown in fig. 108, in which parallel rays of light are first converged by the positive lens P, and are afterwards made less convergent by the negative lens. Without the negative lens they would have come to a focus at F_1 somewhere between the plate B and P, corresponding to the equivalent focal length of the lens P. If now we trace back the rays forming the focus at B along straight lines we shall find that they do not meet the parallel light which first entered the lens until a point is reached a long way in front of the positive lens P—much further, in fact, than is indicated in the figure by the point A, which for the sake of clearness has been placed far to the left. Thus we see that by introducing the negative lens we are virtually working with a lens of very long focus, although the camera

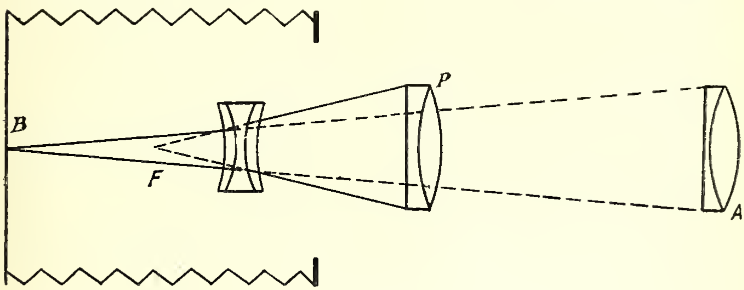


FIG. 108.

extension is very little in excess of that required for the lens P alone. In other words, this combination, the telephoto lens, has its nodal points a long way in front of the lens—*i.e.* it possesses a great equivalent focal length compared with its "back focus" (camera extension required).

[3] *Variable Focal Length.*—Now by moving the negative towards or away from the positive lens we alter the focal length of the whole lens. The smaller the distance between negative and positive the greater the magnification of the image. Thus we have in the telephoto a lens which gives many focal lengths merely by turning a rack and pinion.

[4] *The Positive for Telephoto Work.*—At the present time telephoto attachments are supplied mostly for use with standard positive lenses. It is necessary that the latter should be of good quality and large aperture (not less than $f8$), because any optical aberrations are

magnified by the negative lens, and the rapidity is likewise decreased by the negative attachment. A portrait lens is suitable for telephoto work, though for general work an anastigmat of large aperture is best. Carl Zeiss makes a special telepositive single lens of great rapidity ($f3$). (See fig. 109.) Its advantages are small bulk, lightness, and fewer reflecting surfaces than the double anastigmat. It is, however, not quite so suitable for architectural work as a double lens. The possessor of a good rapid rectilinear or anastigmat can have a negative attachment fitted. The negative lens is usually mounted in a brass tube which screws into the ordinary flange on the camera front. The hinder part of the tube projects into the camera and carries the negative lens; the positive lens is screwed into the front. Fig. 109A shows the mount supplied by J. H. Dallmeyer, Ltd.; it is typical of those of other firms.

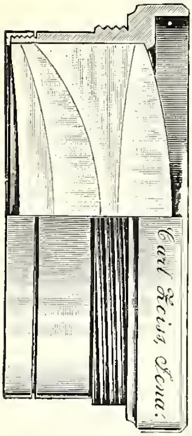


FIG. 109.

[5] *Choice of Negative Lens.*—The focal length of the negative element compared with that of the positive determines the magnification of the image given by the positive lens, for a certain fixed camera extension. The shorter the focus of the negative lens the

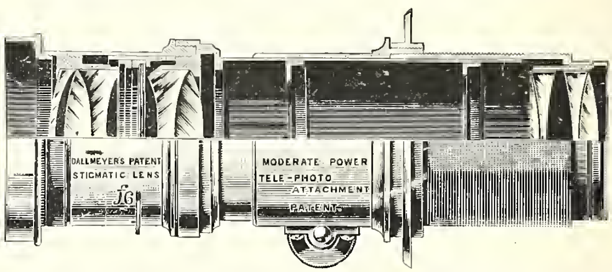


FIG. 109A.

greater the magnification. A negative lens of one fourth the focus of the positive may be called a high power. Its advantage is the lesser camera extension required: its disadvantage, its lesser covering power.

A negative lens of half the focus of the positive (or more than half) may be called a low power. To produce a given magnification, greater camera extension is needed but covering power is greater.

The selection of the focal length of the negative element in regard

to the positive therefore depends on one's requirements. For high magnification in compact form, as in a telephoto hand camera, we shall choose a high power, say negative focus one third of positive focus. For architectural work where small magnification and good covering power are demanded, we shall select the negative one half or more the focus of the positive. For general work a moderate-power negative about half the focus of the positive is recommended.

With the exception of that supplied by J. H. Dallmeyer, Ltd., the negative elements of the leading makers are cemented combinations of three or more lenses. For particulars see the makers' lists.

Properties of the Telephoto Lens.

[6] *Magnification.*—The term magnification is used to denote the number of times the image given by a telephoto lens is larger than the image given by the positive lens alone, linear enlargement being

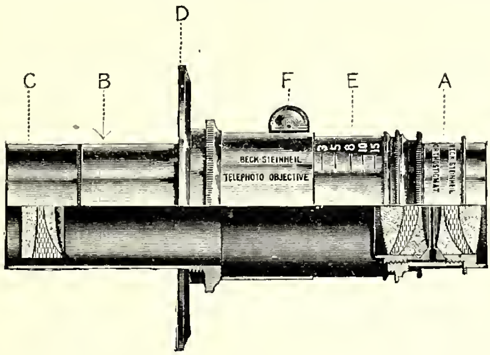


Fig. 110

meant in both cases. Thus a telephoto reproducing a line as 12 ins. which with positive lens appeared as only 3 ins., would be said to have a magnification of 4.

Magnification depends on the separation of the negative and positive lens: the nearer the two lenses the greater the magnification. Many makers engrave a scale on the mount of the lens showing the magnification. See fig. 110, a Beck-Steinheil objective.

To find the magnification, divide the distance of the negative lens from the ground glass by the focal length of the negative lens and add 1. Expressed in formula form:—

$$M = \frac{E}{f_2} + 1.$$

Example: Distance from ground glass to negative lens, 12 ins.; focus of negative lens, 3 ins. Magnification $12 \div 3 + 1 = 5$.

[7] *Focal Length of Telephoto System.*—It is often very useful to be able to calculate this from the focal lengths of negative and positive and the camera extension. The following is the formula:—

$$F = \frac{m\,E + f_1}{\frac{m}{N} + 1}.$$

Where F = focal length required;
m = ratio of focal lengths of positive and negative lens, *i.e.* number of times focal length of negative divides into positive;
f_1 = focal length of positive;
N = ratio of original object to image.

Thus in a positive element of 10 ins. with a 4-inch negative, an extension of 24 ins. and a same size reproduction—

$$F = \frac{\frac{10}{4} \times 24 + 10}{2\frac{1}{2} + 1} = 20 \text{ inches.}$$

Other useful formulæ for the focal length of the whole system are:—

$$F = Mf_1.$$

Where M is the magnification due to the negative lens and f_1 the focal length of the positive.

Also $$F = mE + f_1;$$

m, E and f_1 being as above.

[8] *Covering Power.*—Unlike positive lenses the covering power of the telephoto is reduced by inserting a smaller stop. The diminution is not very great; and if the edges of the field are seen to be black, the plate can be properly covered by increasing the magnification as mentioned in the next paragraph. The following approximate formula for calculating the field covered is given by T. R. Dallmeyer (*Telephotography*, p. 86):—If d_1 be effective aperture of positive lens; d_2 diameter of negative lens; f_1 and f_2 the focal lengths of positive and negative lenses, and E the camera extension—

$$\text{The diameter of field} = \frac{E}{f_2} \times \frac{d_1 f_1 + d_2 f_1}{f_1 - f_2}.$$

Thus if $d_1 = \frac{7}{8}$in.; d_2, $1\frac{1}{4}$ in.; f_1, 6 ins.; f_2, 3 ins.; and E, 9 ins.

$$\text{Diameter of field} = \frac{9}{3}\left(\frac{\frac{7}{8} \times 3 + \frac{5}{4} \times 6}{3}\right) = 10\tfrac{1}{4} \text{ ins.}$$

It is useful to know the smallest disc covered when a lens is stopped down to a given extent. This minimum diameter is given by the following formula, also by Mr. Dallmeyer:—

Minimum diameter of field $= (M - 1)\left(\frac{f_1 d_2}{f_1 - f_2}\right)$, where M is the magnification.

Thus to find how small the field becomes when the positive lens in the previous example is stopped down—

$$(4-1)\frac{6 \times \frac{5}{4}}{6-3} = 7\tfrac{1}{2} \text{ ins.}$$

The diameters of discs necessary to include plates of standard size are given in [1], Chapter III.

Magnification increases covering power enormously. If, therefore, we find the edges of the field uncovered, a slight movement of the negative lens toward the positive will at once put matters right. See pages 110 and 111.

[9] *Depth of Focus.*—When photographing objects fairly close to the camera, as in portraiture, the telephoto lens compares advantageously with an ordinary positive lens. It possesses greater depth of field—*i.e.* when one point in the object is focussed sharply, the points also rendered sharp are further away in each direction from this point than would be the case were an ordinary positive lens of the same equivalent focal length being used.

This difference disappears when photographing very distant objects. The advantage of the telephoto lens in this respect is most conspicuous when using it for portraiture or other objects fairly close to the camera. For the methods of calculating the comparative depths of field given by the telephoto lens and a positive lens giving the same sized image the reader should consult *Telephotography*, by T. R. Dallmeyer, pp. 99 to 113. The mode of calculation is to first ascertain the scale of image given by the positive lens alone. This will tell us the magnification needed to produce an image equal in size to that given by the positive lens of long focus with which we are making comparison. In then working out the depths of field (see Chapter V.) we must adopt a circle of confusion of such diameter that when multiplied by the magnification figure the result is not greater than the standard figure, $\frac{1}{100}$ of an inch. This for sharp pictures: in portrait and other pictorial work a greater circle of confusion would be admissible, because the picture is not closely examined.

[10] *Angle of View.*—The photographer should note that provided his plate be large enough to receive the highest magnified image given by his telephoto lens, the angle of view is the same whatever the magnification: the image produced by the positive lens is simply more or less enlarged by the negative attachment.

Exposure in Telephotography.

[11] *Rapidity.*—The greater the magnification the less the rapidity of the telephoto lens. The relation between the two is very simple. To find the *f* number of the whole telephoto system, divide the *f* number of the positive lens by the magnification. Thus if the positive is being worked at *f*11 with four times magnification, the real rapidity is *f*44, and exposure must be given on this basis. To put the same thing another way. If you know what exposure you would give with a certain stop, you must multiply the number of seconds by the square of the magnification. Thus if 5 seconds would be right for the positive lens alone, $5 \times 4 \times 4$ (or $5 \times 16 = 80$) must be given when magnifying four times.

According to Frank B. Dobbins, the author of *The Photo Miniature*, No. 30 (an excellent brief treatise on practical telephoto-work), correct exposures are obtained in half the time indicated by the above rule.

It will be interesting to hear the opinions of other workers on this point. Probably atmospheric conditions have a good deal to do with the discrepancy: Mr. Dobbins' exposures were made in America.

In the case of some telephoto attachments the magnification is not engraved on the mount. It must be found by the simple rule given in [6].

[12] *Focussing* in telephotography can be done by moving either the ground glass screen or the negative lens. The latter is the more sensitive movement, and in view of the small apertures generally necessary, is to be preferred.

The proper course is to decide first what magnification shall be used, to set the negative attachment scale to this figure, and to rack the camera back also to the right point. The rule for camera extension is as follows:—Subtract one from the magnification and multiply by the focal length of the negative attachment: the result is the distance from negative lens to ground glass. Thus, with 3-inch negative lens and magnification of 5, distance between negative lens and screen must be 12 ins.—*i.e.* $(5 - 1) \times 3 = 12$). As the negative lens usually

projects an inch or two into the camera, the camera extension is always a little more than this.

Having got negative lens and screen into position, final focussing is done by moving the negative lens.

There is one little point which helps in getting sharp pictures. A partial turn of one of the lenses of the positive objective frequently improves the definition. A quarter or half turn is generally enough. Certain rapid portrait lenses have a special adjustment to serve this same purpose.

[13] *How much to stop down.*—Theoretically no lens should be used at a less effective aperture than *f*71 (Lord Rayleigh), but the effects of diffraction which should make their appearance at this and smaller apertures do not trouble in actual practice. For the sake of rapidity, however, it is well to use as large an aperture as possible.

It is well to be content with moderate magnification. The less magnified image does not call for such high optical qualities in the positive lens, and the shorter time of exposure diminishes the chance of unsharpness from vibration. A telephoto lens is like an optical lantern: you can project a 20-feet picture with an oil lamp, but it is more satisfactory to make the disc 6 ft. diameter.

Apparatus for Telephoto Work.

[14] *Camera and Tripod* deserve a few words, because on them much of the success depends. The camera should be one of the square bellows pattern with a rigid front and a movable back. As it will generally be used at full extension, its rigidity when thus extended is important. This is more easily accomplished in the square back-racking camera. The tripod should be of solid construction with a large top.

[15] *For architectural work*, such as the photographing of detail, the camera back should possess very ample swing. A tilting board also is almost a *sine quâ non*. Few cameras possess the necessary range of swing, and we therefore quote Ernest Marriage's device for getting the necessary movement from *The Photogram*, 1898, p. 10. Mr. Marriage says:—

"Figs. 111 and 112 show how this amount of swing can be arranged for in such a way that there are no projecting stays when the camera is closed.

"A, B, C and D are binding screws. The slotted stays are filled in

black. The strut *f* is only dotted in for convenience; it has to be bent in the middle (as shown at the side), in order to clear the clamp C. The clamp A in fig. 111 is shown screwed into a socket out of the way; when in use it is screwed in at the hole A¹. Fig. 112 shows the position of the camera back and stays when the back is swung 30°. For a slight amount of swing it is not necessary to alter the positions of the screws; the stay H should be pushed for-

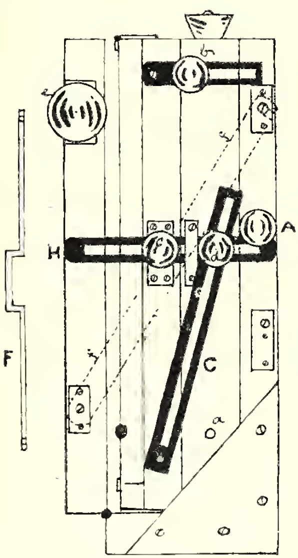


FIG. 111.

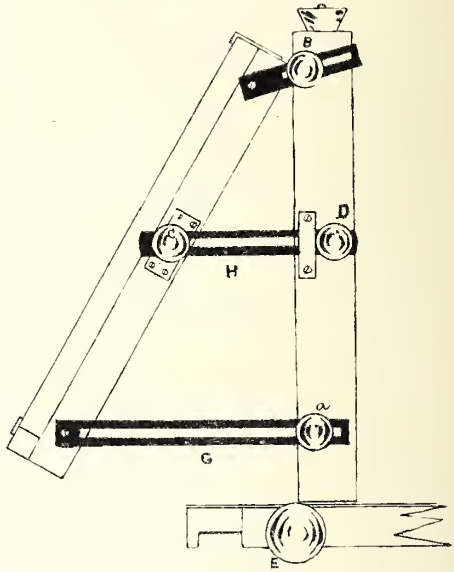


FIG. 112.

Sketch of $7\frac{1}{2} \times 5$ in. camera. Quarter natural size.

ward as far as it will go, but otherwise the arrangement in fig. 111 can be adhered to.

"A telephotographic lens requires rather different treatment from an ordinary positive lens, on account of the narrow angle of view it embraces. It will always be found best to keep the telephotographic lens opposite the centre of the plate. To photograph bits of architectural detail above the camera it is therefore necessary to tip the camera (preferably by means of a tilting table) and swing the back to the perpendicular, instead of resorting to the usual expedient, and simply raising the lens. A telephotographic lens used with a moderate camera extension does not cover a large plate; it is, therefore, not practicable to raise the lens much, but the camera back may be swung

over 20° without seriously affecting the definition, if the positive lens is stopped down to *f*16 or *f*22.

[16] *Tilting Table.*—"In practice it pretty soon becomes obvious that some means of tilting the camera other than altering the legs of the tripod are required. A ball and socket joint between the camera and stand is useless for this class of work; a tilting table is much more reliable. Fig. 113 is a diagram of the most convenient form, showing the table in two positions. The stay *c* is slotted, so that the points a^1 and b^1 can be brought as near as may be required; the clamps at *a* and *b* slide freely along their respective slots in the sides of the table, so that an angle of 90° is finally obtained. This

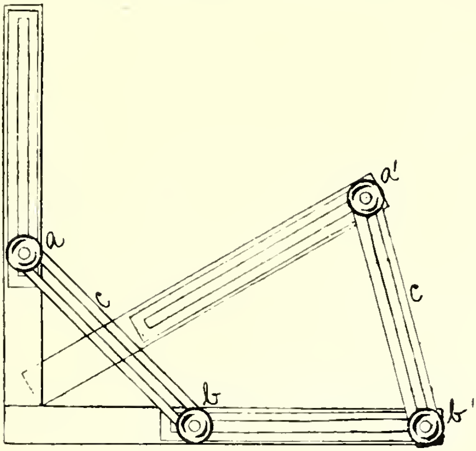


FIG. 113.—Tilting Table. Quarter natural size.

tilting table is a great improvement on commercial patterns that have hitherto been obtainable, and the plan was suggested to me by Alexander Mackie, F.R.P.S."

WORKING METHODS IN LANDSCAPE, ARCHITECTURE AND PORTRAITURE.

[17] *The state of the atmosphere* is an important factor in getting crisp telephotograms. Wind causing vibration of the tripod is not alone responsible for blurred images. Currents of water, vapor, or heated air between the lens and the object affect the definition of the lens. An instructive experiment quoted by Dr. Paul Rudolph is worth making:—"Take a photogram of an engraving or etching

after carefully focussing, and you will probably obtain a fine negative. Repeat the experiment without making the slightest alteration in your adjustments, but on the floor between the object and the objective place a lighted candle. The result will be a partly or entirely blurred negative. The explanation of this experiment lies in the variation of the density of the air caused by the rising heat of the candle."

"Similar failures," continues Dr. Rudolph, "may occur if a photogram be taken of a landscape or of buildings through a window from which a current of the warm air of the room is passing, and the same happens if the hot air above a chimney should rise between the objective and the object. Success in telephotography therefore depends very often upon extraneous circumstances, and even with the greatest care it is not always possible to avoid failures. Landscapes and distant buildings should therefore be photographed only when the air is calm and clear, but hot days should be avoided."

On this point also we make room for the following weather hint from *Practical Notes on Telephotography* (R. & J. Beck, Ltd.):—

"To judge of the clearness of the atmosphere is not always so easy as might be supposed; a brilliant sun, even on a slightly hazy day, may give an impression of superabundance of light which will be misleading. The best method of judging is by examining distant black shadows, and if they appear jet black, without a tendency to greyness, and sharply defined, it is a clear day; should they seem grey and not cleanly cut, it is a sure sign of mist in the air."

A yellow-light filter is an aid to sharp definition in misty weather; and in the experience of some workers does not require so great an increase of exposure as when used for photographing near objects.

[18] *Lack of contrast* is a defect often found in telephoto negatives. It is due to the general haze transmitted by the lens. Backed plates and slow development for a strong image are two helps to be borne in mind.

[19] *In interior work* one of the most common difficulties in photographing is that with the low magnification necessary the plate is not covered: a higher magnification gives an image too large for the plate. The remedy is to take a standpoint further away.

The color of stone or bronze detail-work of which telephotograms are made may immensely affect the exposure: deeply recessed carving likewise requires longer exposure.

[20] *In Portraiture.*—To photograph heads life-size it is necessary, as every photographer knows, to have the lens midway between the sitter and the plate, the distance on either side being twice the focal

length of the lens. Therefore with a camera of 40 ins. extension, the longest focal length which can be used is 20 ins., and the distance from lens to sitter must likewise be 40 ins. This, as most know, is much too near for a proper perspective rendering of the features. Yet the man who is tied down to one camera cannot do otherwise, even if he possess a lens of greater focal length.

A telephoto attachment, however, enables him to take up a more distant standpoint and to produce a life-size head with the same or shorter extension of camera.

For suppose we combine this same lens with a 5-inch negative attachment. We can place the camera so as to give an image one sixth the size of the original with the positive lens used alone, and we can place the negative lens so as to magnify six times.

The result will be the same as before—viz., life size. But the distances from sitter to lens and from lens to plate? The first will be $20 \times 7 = 140$ ins.: the second will be $5 \times (6 - 1) = 25$. Thus we see that using our lens as a telephoto we can take a position which gives a far more pleasing perspective, and we require only about two thirds of the camera extension.

The *f* number of the lens when using it thus at close quarters is larger than is indicated by the number on the positive lens × the magnification. In order to find it, proceed as follows:—Ascertain first the equivalent focal length of the whole lens (used at the magnification actually being employed) by the formula in [7]. Note also the camera extension required when focussing on a distant object. Note now the camera extension when focussing at close quarters: it will be greater than the extension for infinity by a certain amount; add this amount to the equivalent focal length, divide by the effective aperture of the positive lens and you have the *f* number of the whole lens. The "effective" aperture is always a little larger than the real aperture. See [7], Chapter IV.

As mentioned in [9], depth of focus is much greater with a telephoto lens used thus than with an ordinary lens giving the same sized image.

[21] The "Adon" lens (J. H. Dallmeyer, Ltd.) consists of a large aperture positive lens and a high power negative lens fitted into opposite ends of a mount the length of which is adjustable. The lens thus acts as an ordinary telephoto, but in addition can be fitted on to the hood of an ordinary lens, which then gives an enlarged image with the same camera extension. This fact makes it a valuable adjunct to the fixed-focus hand camera. Moreover, owing to the

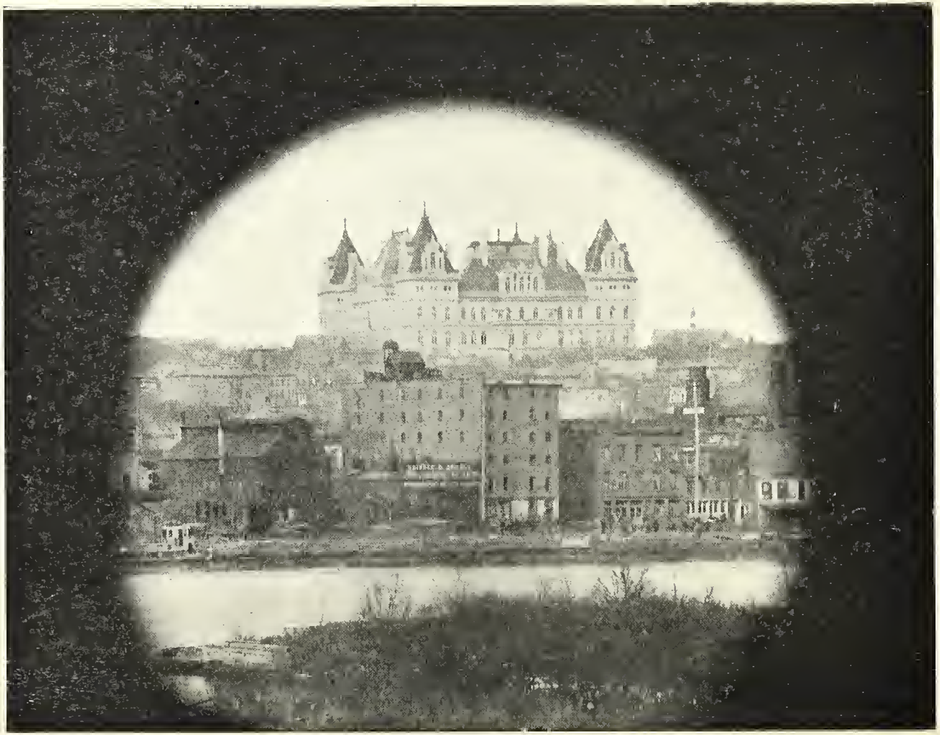


FIG. 113A.—The Capitol, Albany, N.Y. By Mrs. Catharine Weed Ward. Made with telephoto-lens at moderate magnification. See p. 103.

B. J. almanac, 1914, p 573

Fig. 113B.—The Capitol, Albany, N.Y. By Mrs. Catharine Weed Ward. Made with same lens as fig. 113A, but at greater magnification and consequent increased covering power.

large aperture of the front positive lens of the "Adon," the loss of illumination when an ordinary lens is converted into a telephoto by its addition is less than when a negative attachment is used behind. In some cases the original rapidity of the ordinary lens remains undiminished: fig. 114 shows the "Adon" as used to give increased size of image at the ordinary camera extension. A is the ordinary camera lens, B the positive, and C the negative lens of the "Adon." When the distance between B and C is equal to the difference between the focal lengths of these, the whole lens transmits parallel rays, so that the focal plane of the lens A is not altered. But the image produced is magnified in the proportion of the focus B to that of C—*i.e.* if B is twice the focal length of C the image is magnified twice (linear).

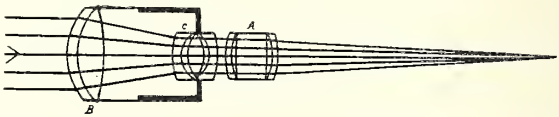


Fig. 114.

By bringing B and C nearer together the rays passing through C are divergent, and therefore a larger image than before is produced further away than F. The illumination is less.

By separating B and C further than required to transmit parallel rays the image is received nearer the lens than F. The magnification is now less, but the illumination greater than in the normal position shown in fig. 114. With the lens arranged thus an enlarged image of objects near to the camera may be formed at the focus of the lens A—*i.e.* at F. This, again, is of importance to the fixed-focus hand-camera worker.

The field covered by a lens fitted with an "Adon" attachment depends on the character of the lens. Lenses in which the components are widely separated will not cover their full size of plate at the "infinity" focus. By adjusting the separation of the "Adon" and the camera extension in accordance therewith, the whole plate can be covered. The circle of illumination given when the "Adon" is used alone is considerably greater.

CHAPTER XI.

CHOOSING A LENS.

[1] *The price of a photographic lens* ranges from half a crown—for which sum a good spectacle lens can be bought—to many pounds. Putting aside for the moment the portrait lens—which is a special instrument for a special purpose—we may state roughly that the money expended on a lens secures great efficiency in one or more of the following points:—(1) Rapidity. An ordinary spectacle lens must be stopped down to $f22$ or thereabouts to give reasonably good definition; a view lens will work well at from $f16$ to $f11$; a double lens (R.R.) has an aperture of $f8$; most of the anastigmats work at $f6$, and some, such as the Unar and Protar, at $f4{\cdot}5$ and $f3{\cdot}6$. For some work, *e.g.* hand camera, the extra rapidity of the expensive anastigmat is worth all it costs: for other, *e.g.* architecture, it is not. But the claims of the anastigmat concern also the other factors in the price.

(1) Freedom from aberrations when used at the largest aperture supplied. Most lenses give reasonably good pictures when stopped down considerably. The ability to give—at full aperture—negatives which will stand subsequent enlargement is a property which can only be secured at increased cost. See the tests which an ordinary R.R. lens—anastigmat—ought to pass (Chapter VIII.).

(2) Covering a plate of larger size.—Many lenses when stopped down cover a much larger plate than at full aperture. This is true of nearly all the modern anastigmats which can thus be used as "wide angle lenses." For example, the writer ordinarily uses an anastigmat of $5\frac{1}{2}$ ins. focal length (intended for a quarter-plate) on a half plate which it covers perfectly at $f16$: stopped down to $f32$ it covers a 10×8. To the architectural photographer this is a very valuable property. It is not possessed by view lenses, and not to a great extent by double lenses of the *ordinary* type.

(3) Several focal lengths with the one lens.—Each component of a rapid rectilinear has a greater focal length than the whole lens—generally about twice the focus of the whole lens. A lens which can be taken to pieces and its front and back combinations used in this way as landscape lenses of long focus is called "separable." At the present time opticians are making lenses which are "unsymmetrically separable"—*i.e.* one combination is only one and a half or one and a quarter the focal length of the whole lens, whilst the other is twice the focal length. Thus the purchaser of a 6-inch lens gets, say, a 9-inch and a 12-inch single lens. Some lenses are not separable in this way; others can be thus used if the single lenses are stopped down; others allow the single lenses to be used with the largest apertures in the mount. The makers' catalogues generally state whether lens is separable or not. *N.B.*—The reader should note that the *f* numbers on the mount have other values when the single lenses are being used. (See Chapter IV.) Some makers mark a double scale on the mount.

(4) Flatness of field means an increased price. There are still some who write of the virtues of the lens with a round field, and it is a fact that this defect functions advantageously in certain cases. But, generally speaking, it is well to know that an object which is in focus at the centre of the plate would still be sharp if the camera were shifted round so that it fell at the edge of the plate.

The above facts will help the purchaser to decide for himself. If he essays landscape work pure and simple, he may find a set of spectacle lenses or a single achromatic lens sufficient. But for rapidity and critical definition, he must get the more expensive anastigmat. The cost of the latter is somewhat discounted by the facts mentioned above, that they generally cover at a wider angle when stopped down, and that they are often separable into perfect landscape lenses. We will now briefly refer to the use of lenses of various types, referring the reader for futher details to Chapter VIII.

[2] *The spectacle lens* is usually about $1\frac{1}{2}$ in. in diameter, and can be obtained of any focal length from 6 ins. upwards. It is used with a fairly large stop (*f* 16) and allowance made for the fact that the image seen sharply focussed on the ground glass is not rendered sharply by the plate. This allowance is made in several ways:—(1) The camera is racked in a little after the picture has been focussed. The exact distance is $\frac{1}{40}$ of the focal extensions when the lens is focussed on objects a long way off. (2) A much more convenient

method is that of Robert H. Bow. When focussing, a weak and thin convex lens is inserted behind the spectacle lens. The strength of this supplementary lens is such that it reduces the focal length of the spectacle lens by the $\frac{1}{40}$ mentioned above. Before exposing, it is removed and the plate is of course in the right position for a sharp image. The focal length of this supplementary lens is usually forty-five to fifty times that of the lens to be corrected.

When isochromatic plates and a yellow screen are used, this

FIG. 114A.—"Leafless Trees." By W. Thomas. Taken with a Busch casket lens at f40.

correction is not necessary. In fact, with certain screens and plates it results in fuzzy images being obtained. In this case the simple plan of exposure after focussing without any correction can be followed with satisfactory results.

In portraiture, copying, etc., the correction mentioned above becomes more than one fortieth of the actual focal length, and when copying objects same size as the original (say a life-size head), the correction becomes as much as one twenty fifth. Various rules and tables have been published, but the following from *The Photogram* is

perhaps the simplest. The first line gives the ratio of image to original; the second gives the necessary corrections.

Ratio - -	Infin.	$\frac{1}{10}$	$\frac{1}{5}$	$\frac{3}{10}$	$\frac{4}{10}$	$\frac{1}{2}$	$\frac{6}{10}$	$\frac{7}{10}$	$\frac{4}{5}$	$\frac{9}{10}$	$\frac{1}{1}$
Correction %	2	2·2	2·4	2·6	2·8	3	3·2	3·4	3·6	3·8	4

This percentage correction is on the *actual*, and not on the equivalent focus of the lens. For instance, with a lens of $12\frac{1}{2}$-inch

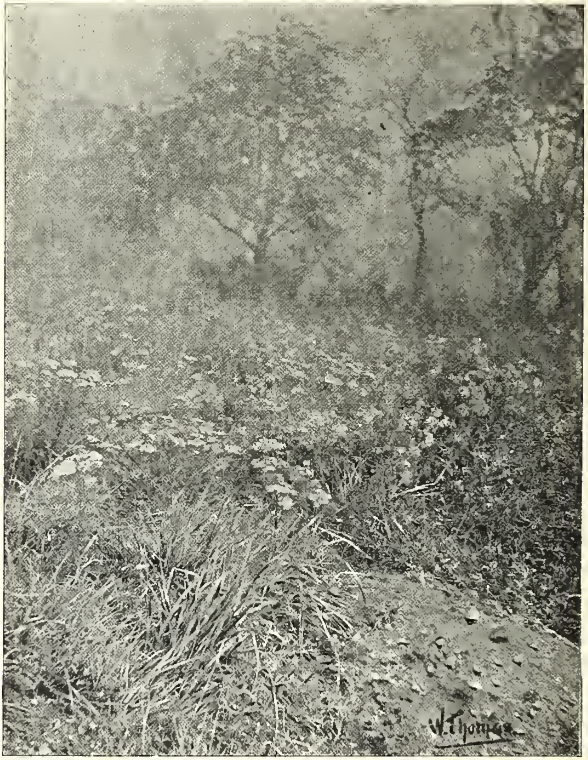


FIG. 115.—"September." By W. Thomas. Taken with a Busch casket lens at $f/40$.

focus, the correction for distant objects (infinity) would be 2 per cent. of $12\frac{1}{2}$-inch or $\frac{1}{4}$ inch; while the correction for the same lens, when copying life-size, would be 4 per cent. of 25 inch, or one inch.

The examples on pages 115 and 116 by W. Thomas show that sharp pictures can be obtained (fig. 114) with the spectacle lens as well as the diffusion of focus seen in fig. 115. In portraiture this diffusion is

an advantage, as witness the bit of work by Miss Evelyn Boden (fig. 116).

[3] *Spectacle Lenses in Caskets.*—Uncorrected or spectacle lenses are put up by several makers in very convenient casket forms. A set of lenses, each in its own brass cell, is supplied with a mount into which they are screwed. The range of focal lengths is very great, as will be

FIG. 116.—Taken with a 12-inch Dolland Monocle at full aperture. By Miss Evelyn Boden.

seen from the table on next page issued with the Busch casket of seven lenses.

One of the disadvantages of caskets is, that when lenses of different foci are used in the same mount, the position of the diaphragm is at its best for one focus only. When only a few (say three) different foci are needed this difficulty may be easily overcome, as it has been in the case of Wray's casket. This had a great vogue at one time, and it is difficult to account for the change of fashion—it is certainly no fault of the apparatus—which has led to its being practically

TABLE OF WORKING APPARATUS—*F* VALUES.

Equiv. Focus. Cm.		10½	11½	**15**	20½	22½	**25**	27½	31	33½	**35**	36½	**45**	55	**65**	**75**	
Inches.		4	4⅜	**6**	8	8¾	9⅞	10½	12	13	**13 10/16**	14	**17¾**	31¾	**23⅝**	**29 9/16**	
With Stop.	The Working Aperture is—	And the *F* values are—															
1	19 mm.	*f* 5·5	*f* 6	*f* 7·9	*f* 9	*f* 11	*f* 12	*f* 13	*f* 14	*f* 16	*f* 17	*f* 18	*f* 19	*f* 24	*f* 29	*f* 34	*f* 39
2	15 ,,	*f* 7	*f* 7·5	*f* 10	*f* 11	*f* 13·5	*f* 15	*f* 16	*f* 18	*f* 20	*f* 22	*f* 23	*f* 25	*f* 30	*f* 37	*f* 43	*f* 50
3	12 ,,	*f* 9	*f* 9·5	*f* 12·5	*f* 14	*f* 17	*f* 19	*f* 21	*f* 23	*f* 26	*f* 28	*f* 29	*f* 30	*f* 38	*f* 46	*f* 54	*f* 60
4	9 ,,	*f* 11·7	*f* 13	*f* 17	*f* 19	*f* 23	*f* 25	*f* 28	*f* 30	*f* 35	*f* 37	*f* 39	*f* 40	50	*f* 61	*f* 72	*f* 83
5	6 ,,	*f* 17	*f* 19	*f* 25	*f* 28	*f* 34	*f* 37	*f* 41	*f* 46	*f* 52	*f* 56	*f* 58	*f* 61	*f* 75	*f* 91	*f* 108	*f* 125
6	2·8 ,,	*f* 37	*f* 41	*f* 53	*f* 61	*f* 73	*f* 80	*f* 89	*f* 98	*f* 110	*f* 120	*f* 125	*f* 130	*f* 160	*f* 196	*f* 230	*f* 265

The focal lengths shown in heavy type are those of the single lenses: the others of combinations made with pairs of them.

neglected. The lens-tube, of brass or aluminium, extends telescopically by a single slide, and is closed when using the shortest focus lens, partly extended for the medium, and fully extended for the long focus. Three uncorrected ("spectacle") lenses are supplied, one in the back of the mount, the others in a leather case, and the diaphragm is an iris, marked with a separate set of *f* numbers for each lens. The half-plate set has lenses of $6\frac{1}{2}$-inch, 9-inch, and 12-inch focus.

The general conclusion on these caskets is that they need a little more care in use, and cannot of course give the supreme results in the way of definition rendered by more expensive lenses. But they are extremely useful, and we should advise every man who is beginning photography, or who has one lens and wishes to buy another, to take one of these caskets instead of a single lens. He will eventually want more perfect tools, but, meanwhile, he will gain a knowledge of the use of lenses generally, which is impossible to the man who only uses complete lenses, and he will gain a versatility in selecting subjects, and in arranging his subject within the space of the plate, that will be invaluable in picture-making. The price of a casket of spectacle lens varies from £1 5s. to £3 3s.

[4] The view lens (known also as the "landscape" or "single" lens) consisted until recently of a meniscus lens cemented to a negative correcting lens. It usually worked at *f*16, although more rapid lenses have been made by Dallmeyer. Its simple construction permitted the removal only of chromatism and spherical aberration and not of astigmatism. Now, however, single lenses are made which give a practically anastigmatic field over a wide angle at fair rapidity—*e.g.* the Zeiss convertible single anastigmat (Series VII.), which covers an angle of 85° at 12·5. See "New Achromats," [14], Chapter VII.

Now, too, single lenses giving far less distortion are available, especially when they are fairly long in focus.

This indeed is the sole condition for using single lenses for all purposes. They give a barrel shape distortion at the edges of the plate, which, however, is of no importance in landscape work. In architecture, where it would be a serious drawback, it can be avoided by selecting a lens of such focal length that the edges of its field fall outside the plate.

The single lens is excellent for portraiture, especially of large heads. J. H. Dallmeyer, Ltd., supply a special type of their rapid (long focus) landscape lens for this purpose: it works at *f*10. Very often the possessor of a view lens can improve it for the purpose of portraiture by opening out the apertures. See [5], Chapter XII

[5] *The Rapid Rectilinear Lens,* also known as doublet, etc., does not distort like the single lens, is more rapid, working at *f*9 or *f*8, and owing to its greater number of glasses can be more perfectly corrected, so that except for astigmatism it is generally free from the various defects mentioned in Chapters VI. and VII. When stopped down it will usually cover a plate somewhat larger than that covered at full aperture.

The two components of a rectilinear can be used as single lenses of double the focal length or thereabouts, though small stop must generally be used. This is a point which should often decide the choice of a lens. The long focus is an advantage in landscape work; but very often the purchaser of a R. R. finds that his camera will not extend far enough to enable him to use the single combination. Hence here is a useful rule when buying a R. R.:—"Choose a doublet of such focal length that your camera will just accommodate its single combinations when focussed for moderately distant objects."

The R.R. has been truly called the "universal" lens, because it is fairly suitable for all kinds of work; and for the photographer who is restricted to one lens the R.R., or its more perfect form the double anastigmat, is the best all-round lens.

[6] *The Anastigmat* (known also by many titles, such as Stigmatic Plastigmat, Platystigmat, etc.).—The chief advantages of a lens of this kind over a rapid rectilinear are rapidity (*f*6, *f*4), extremely fine definition over a very wide flat field and at a large aperture, portability, and freedom from the chief defect of the R.R. astigmatism.

The great covering power of the anastigmat is an immense advantage. The front of the camera may be raised to any extent without fear of leaving the bottom of the plate uncovered; and the lens can be used to include a very wide angle on a larger plate.

The great flatness of field and large aperture of the anastigmat together call for greater care than is usually given to the fitting of the lens in the camera; otherwise the lens may appear inferior to an R.R. The plate should be as parallel as possible with the camera front; if it is not, the sharpness of the image in some parts is sacrificed; the plate, too, must come into the same position as the focussing screen (see Chapter XIII.), or the results may be wofully out of focus. We are speaking now of the anastigmat used at its full aperture. When stopped down, these refinements of adjustment are no more necessary with it than with the R.R.

The fineness of definition of the anastigmat qualifies it especially for negatives which are to be enlarged.

To the user of the small camera who wishes to get the sharpest possible enlargement it is invaluable.

As regards choice of the focal length of the whole anastigmat and of its two components (when they can be used separately), readers should consult the makers' lists.

[7] *The Wide Angle Lens.*—In Chapter III. we explain what is meant by the term "wide angle lens," about which much misconception has existed. At the present time the double anastigmats when slightly stopped down constitute our best "wide angle lenses," and for obtaining views in confined situations are extremely valuable.

The position of the camera in relation to the subject is of great importance when a very wide angle is being included on the plate. It is easy to get an exaggerated and grotesque perspective. Sometimes this can be avoided by a proper choice of position. Sometimes it cannot.

The following notes and photograms by F. J. Allen, M.A., M.D., are given here (from *The Photogram*, November 1901) as bearing on this point:—

"The unpleasing perspective of a wide angle view is not caused by a defect in the lens, but is in the nature or position of the subject photographed, which the lens reproduces in mathematical perspective. Nevertheless, a wide angle lens has a defect: it is contrived to give good average definition over a large area; but in order to secure definition at the margin as well as the centre of the plate, the surfaces of the lens have to be so modified that the focus is nowhere absolute. Therefore a narrow angle lens is preferable when minute detail has to be rendered.

"In explaining the apparent anomalies of wide angle views, certain points in the physiology of vision may assist us. The human eye embraces an enormously wide angle of view, only a little short of 180° or a hemispherical panorama. Such a view is far beyond the reach of the widest angle photographic lens, and could only be taken on a spherical concave surface. But the retina has such a surface; and for this and other reasons about to be mentioned, we get a perspective in the eye which is very different from that produced on a flat plate. There are anomalies in both cases, but they are opposite in kind.

"Fig. 117 is an outline of a section through an eye, with lines showing approximately the direct path of rays of light. The lines Bb and Cc include an angle of 90°, which would be wide for photographic purposes, corresponding to that of a 5-inch lens used on

a 10-inch circular plate. But such an angle is narrow for the eye; the lines *D d*, *E e*, include an angle of 160°, which is well within the capacity of the retina. The position of the retina, occupying the inner surface of the eyeball, is indicated by the outline; while the horizontal line at the bottom of the diagram represents the relative position of a photographic plate, if that were used with the same lens. It will be seen that the image on the retina must differ widely from that on the photographic plate. For instance, the angles *a o f*, *c o f*, are equal, and the parts of the image included in these angles should also be equal; but on the retina the outer angle covers *less* surface than the inner, while on the flat plate the reverse is the case, *c f* being distinctly *greater* than *a f*. The discrepancy increases toward the margin of the view, so that the angle *e o c* covers a narrow

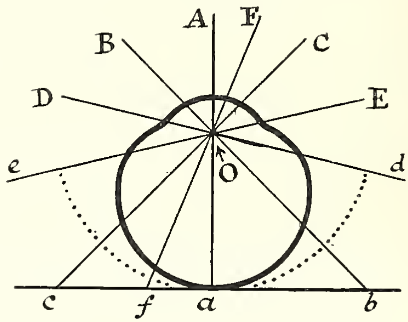


Fig. 117.

space on the retina, whereas on the plate it would reach some inches beyond the diagram.

"Again, the retinal image is out of focus in every part except the very centre of vision, *a* in the diagram. To secure a symmetrical and evenly focussed image the retina would have to be in the position of the dotted line, everywhere equidistant from the optical centre, O, and the lenses would have to be spherical. But our vision is acute only in the centre of the retina, at a small spot called the *fovea centralis*: from this spot outwards the sensitiveness diminishes rapidly. Thus distinctness of image and acuteness of perception are both limited to the middle of the retina; and a normal eye gets a *definite* impression of the centre of any object which it looks at, and an *indefinite* impression of the surrounding parts. As to the *shape* of the retinal image, that matters little: the retinal image is only a collection of diagrams, which the brain can interpret,

giving to each detail its position—not on the retina, but in the outer world.

"Although the retinal image differs so much from a photographic one, it is possible to get a correct impression of the latter by placing the eye in the same relative position that the lens occupied in taking the picture. When, however, the same picture is viewed at a greater distance, the perspective is disturbed, because the peripheral part of the view which in nature would fall upon the periphery of the retina, falls on a more central part. It follows that a wide angle picture of small size is more unnatural than a larger picture taken at the same angle, which covers a larger area on the retina. So a view which looks absurd on a lantern slide, may become tolerable when projected on the screen.

"The kind of subjects that can be taken without any peculiar perspective are those which lie in one plane normal to the line of sight. Such are not only walls, but also pavements, ceilings, slabs, and monumental brasses, if the camera be turned lens-upwards or lens-downwards as the case may require. Even the widest angled lens gives a symmetrical reproduction of such subjects. But any details not in the said plane, if they lie toward the periphery, are reproduced in profile. For instance, an archway near the margin will show too much of its inner surface, and a figure in relief will seem to project overmuch.

"A special instance of this kind of distortion is liable to occur where a long building, seen in face, has a series of projections or recesses, such as piers, buttresses, or windows; the projections or recesses show more and more of their sides as they approach the margin of the picture, and this may give the impression that they, and the part of the building to which they belong, are slewed round and bent away from the observer.

"The farther a subject departs from a normal plane, the greater will be the perspective displacement of its lines; and it is therefore a useful rule, when pronounced geometrical forms occur in planes other than normal, to be cautious of placing them near the margin—and especially the corners—of the plate, where the displacement is greatest.

"In views of exteriors it is inadvisable to get the *nearer top corner* of a building in pronounced perspective close to the margin, where it always looks too acute and prominent. It is often better to leave the corner out of the view; the wall in perspective without the corner may be inoffensive.

"One may go further and say that a corner projecting forwards may have an offensive perspective in any part of the picture, if it be too near the camera. This applies even to narrow angle views.

"There is perhaps no class of subjects in which the perspective at the margins may be more difficult to manage than in wide angle interior views; and yet a narrow angle view may sometimes give but a poor idea of the architectural effect. To exemplify the possible treatment in such cases, I have made many experimental exposures on an unusually difficult interior,—that of Tewkesbury Abbey, in

Fig. 118.

which a wide angle view is necessary to convey a correct idea of its space, while the very tall columns and their circular capitals are liable to assume an unpleasing perspective. The three views, figs. 118, 120, and 121, were taken with the same lens, a Ross wide-angle-symmetrical of 5 ins. equivalent focal length. A 5-inch lens is usually considered most suitable for a quarter-plate; but I have used it on a whole-plate in fig. 118, at the same time raising the front and swinging the front of the camera. Fig. 120 is from the same negative, but with so much of the margins omitted as to leave a half-plate print. Fig. 121, printed quarter-plate size, is taken from a different

point, more suitable to a narrow angle view. These three views, though taken with the same lens, are respectively wide angle, moderately wide, and narrow angle: each picture has perhaps its merits and defects, but I should be sorry to condemn either of them; and for the wide-angle view I venture to say that it conveys a more adequate idea of the building than either of the narrower angle views. Fig. 119 is taken with the 5-inch lens on a whole plate, the subject

FIG. 119.

being purposely arranged to give the absolutely grotesque effect often noticed in commercial views of Tewkesbury Abbey.

"When a building is photographed absolutely upright, the perpendicular lines sometimes appear to splay outwards at the top, owing to absence of the natural perspective convergence to which we are accustomed in the real thing. The wider the angle of the picture, the more striking is this illusion: it is therefore an advantage, when the subject will admit of it, to allow a little slant to the swing-back, so that the perpendicular lines may converge very slightly upwards.

"Fig. 122 (Church-tower, Shepton Mallet, taken with a $5\frac{1}{2}$-inch lens, medium angle, on a whole-plate whose corners are not quite

covered) shows several perspective effects which should be, and often can be avoided, even in a wide angle view. The building is taken cornerwise, so that no part of its surface is in a normal plane. The

Fig. 120.

Fig. 121.

corners project into the foreground, so as to look unduly large and prominent. The tower being very near the camera, is so exaggerated in size as to dwarf the body of the church into a mere appendage.

The angles at the top and bottom of the tower are too peripheral, and are therefore rendered very acute. But it may be noticed that the point of view is on a level nearly half-way up the tower, so that the perspective displacement is equalised at the top and bottom: this is not so bad as when the camera is near the ground, and the front

FIG. 122.

raised, so as to throw most of the displacement on the upper part of the building. All these faults disappear, however, when the picture is viewed from a very near point, with the aid of a lens in the case of persons with long sight.

"The arrangement of the subject in fig. 122 is, of course, unpictorial, and it would be preferable to select another point of view. But when, as in this instance, the most desirable views are blocked, it

may be pardonable to take even awkward wide angle views as architectural studies. There are other instances where narrow angle views can give no adequate impression of the architectural effect: this is especially the case with spacious interiors. It is often possible, by observing various precautions, some of which I have mentioned, to produce agreeable pictures at wide angles. And in any case it may be said that if a wide angle picture has an unpleasing perspective, the fault is not in the lens, but in the subject or the photographer."

[8] *The Portrait Lens* is a special lens giving very fine definition at a very large aperture over a narrow angle. See [19], Chapter VIII.

[9] *The Dallmeyer Bergheim Lens* is a lens made by J. H. Dallmeyer, Ltd., specially for the purposes of portraiture. It is composed of a single front lens of positive focus in combination with a single back of lens of negative focus. The distinguishing features of the lens are (1) peculiar delicacy of definition, due to spherical and chromatic aberration left in the lens; and (2) variation of focal length, by altering the distance between the two single lenses. For example, No. 2 of the series can have focal lengths between 25 and 40 ins. (requiring camera extensions of only 15 to $22\frac{1}{2}$ ins.), and works at from *f*8 to *f*12 according to the focal length. In order to determine the *f* number at any given extension the makers recommend the following method :—Note the camera extension when lens is focussed on a *distant* object. If now focussed on the object in the studio, it will be found that the camera back has to be racked out; add the amount thus racked out to the equivalent focus for the time being—*this equivalent focus is engraved on the mounting of the lens for various separations between positive and negative elements*—and the temporary focus thus found, divided by the aperture of the stop used, gives the focal ratio or guide to exposure.

A similar softness of definition can be introduced with the Dallmeyer Patent Portrait Lenses and the Dallmeyer Portrait Stigmatic (Series I.) by unscrewing the back. See also softening definition in Chapter XIII.

[10] *The Telephoto Lens* is described in Chapter X.

CHAPTER XII.

FOCAL LENGTH AND PERSPECTIVE.

[1] *Effect of Focal Length.*—The focal length of a lens plays only a secondary part in taking photograms in pleasing perspective. The main factor is the point of view selected for the camera. This fixed, perspective is fixed also. No matter what lens be used, the perspective rendering remains unaltered. The only result of altering

FIG. 123.

the focal length is to reproduce the scene on a larger or smaller scale, the practical effect of which is to include a lesser or greater amount of the subject on the plate.

First, let us give an illustration of this in practice. Figs. 123, 124, and 125 are all taken on a half-plate from exactly the same standpoint. The camera was not moved. The only difference was in the focal

length in the lenses. Fig. 123 was made with a lens of 8 ins. focus; fig. 124, with about a 9-inch; fig. 125, with a 14-inch. Examine

FIG. 124.

FIG. 125.

them closely and it will be seen that the perspective in each is the same, though fig. 123 is what would be called a wide angle picture. If, how-

ever, we enlarge the central portion (outlined in white) corresponding to fig. 126, it is seen that the two views are identical in every respect, save for the sun-blind, which was raised after the first plate had been exposed (fig. 125). So much for the fact demonstrated—*alteration of focal length influences only the size of the subject and the amount included—not the perspective.*

[2] *Effect of View Point.*—Now let us demonstrate the more important factor. Fig. 127 is a view made from a standpoint as close to the building as a lens capable of receiving rays over a wide angle will allow. Fig. 128 is from a more distant standpoint. It might have been

FIG. 126.

photographed with the same lens and enlarged. Actually it was taken with one of longer focus, a difference, as we have just seen, which affects only the scale of reproduction. The two pictures are adjusted so that the vertical height from the street to the spire over the clock is the same in each case. Now compare the two results. In fig. 127 the building appears distorted, the right hand top corner appearing to bulge out; the trees appear immensely high in comparison with the building, and the adjoining block looks dwarfed into insignificance. All this is the result of the too near standpoint. When, as common sense dictates, we take up our position so that we can view the building easily and pleasantly without looking up very much, we get the natural effect of fig. 128. Here, then, we lay

FIG. 127.—This and the next illustration are from Loescher's *Leitfaden der Landschafts Photographie.* (Berlin: Gustav Schmidt.)

FIG. 128.

our finger on the evil of the short focus lens. It enables us to get photograms like fig. 127. With longer focus lenses we should be compelled to go further away.

[3] *View Point and Perspective.*—In order to explain exactly how the point of view affects the perspective of the picture, we may quote an admirable article by T. F. Bell in *The Photogram*, 1898, p. 253:—

"Let a diagram be made as fig. 129, representing four upright posts at a distance apart, as street lamps. If the eye is at the point A, rays of light coming from the tops and bottoms of post No. 4 will cut the first post as shown at E and F, and if No. 1 post is full size on the picture, No. 4 post will be the height of from E to F on No. 1. If the standpoint is changed to B whilst the first post is kept the same size in the picture by means of a shorter focus lens, No. 4 post would be reduced, as shown on No. 1 post, by the lines drawn from B to

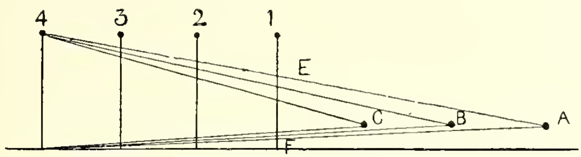


FIG. 129.

No. 4. Moving to C still further cuts down the distance if No. 1 is kept to the same size, and all parallel lines, such as the ridge and ground lines of houses, will be more or less cut down in this way or made to converge so much more quickly, according to the angle at which they recede into the picture, making near parts appear very large and distant parts very small. This is the effect of a short focus lens, which, if properly made, does not distort the view, as is often stated, but simply reproduces it from the point at which the lens is used. When close to the view a short focus lens is usually required to include it, and whether short or long focus, the perspective will be the same.

"It is often stated that pictures made with a short focus lens appear in natural perspective if viewed from a distance away from the print equal to the focal length of the lens used. Theoretically that is true, but very few people will view prints in this way. The advantage of the narrow angle of view (produced by a lens of long focus or by using only the middle of the same plate when a lens of short focus is used) has the advantage that the eye may move away

from this theoretically correct position without creating the feeling of false perspective.

[4] "*The moral* is that for pictorial and pleasing photography a lens of narrow angle is preferable because it compels the photographer to select his view point some distance away, and prevents him weakening the interest of his pictures by including too much on the plate. A safe rule is to have the focal length not less than the diagonal of the plate—*i.e.* $5\frac{1}{2}$ inches for $\frac{1}{4}$-plate, $7\frac{1}{3}$ inches for 5×4, 8 inches for $\frac{1}{2}$-plate, and $10\frac{3}{4}$ for $\frac{1}{1}$-plate. But it may very well be much more than this; some leading pictorial workers using $\frac{1}{4}$-plate cameras fitted with lenses of 12 or 15 ins. focal length."

CHAPTER XIII.

FOCUSSING.

[1] *How to Focus.*—As explained in Chapter IV., objects at different distances from—and not very far from—the camera are obtained equally sharp by stopping down. Focussing consists in adjusting the position of the plate so that the desired sharpness is obtained. The whole of a near subject cannot usually be rendered sharply with the lens at full aperture. We must focus one point and then stop down. The beginner will ask: Which point is to be focussed? If it is desired to get the whole picture as sharp as possible, we reply as follows, and refer the reader who wishes to be informed on the pictorial aspect of focussing to paragraph [4] and to his own taste.

[2] *Focussing sharply.*—Most views consist of an immediate foreground, say a gate, and an object in the distance, say a chimney. We want to get both these sharply focussed on the plate, and, generally, we want to use no smaller aperture than is necessary to do this. We proceed thus: With f8 (or the largest aperture) we focus the gate and then the chimney. We find that we must move the lens a certain distance, and that we cannot get both sharp at the same time. We put in the next stop, say f11, and again focus, first the gate and then the chimney. Again a distance through which the lens must be moved; still impossible to get both sharp together. We go on in this way, inserting stops f16, f22 or f32, until we find that the movement for getting first the gate and then the chimney into focus is practically *nil.* As we stop down, the picture becomes darker, and in order to work with ease it is almost necessary to use a magnifying glass (see below). Suppose, having obtained both sharp, we turn back to our largest aperture, we shall find that neither gate nor chimney are exactly sharp, but that some object between them is sharply focussed. As we would expect from the formulæ on depth of focus this point is a good deal nearer to our imaginary gate than to

the distant chimney: whence we take the hint that our practice in acquiring skill in focussing is to be in fixing upon the point, beyond our immediate foreground, which when focussed with a large aperture will give sharp definition in other planes when the lens is stopped down. To judge accurately of this point is merely a matter of practice.

In the usual run of field landscape work the foreground is focussed and the other planes of the picture brought into focus by stopping down, but when photographing subjects such as groups, animals, flowers and others, where the danger of movement compels as short an exposure as possible, the tentative method described above is advisable. In the case of some lenses—*e.g.* portrait lenses—it is quite necessary to focus with the stop which is to be actually used. [See Spherical Aberration, Chapter V.]

[3] *Critical focussing—i.e.* getting an extremely sharp focus—demands several conditions:—(1) Exact coincidence in the positions of the focussing screen and plate; (2) an extremely fine surfaced focussing

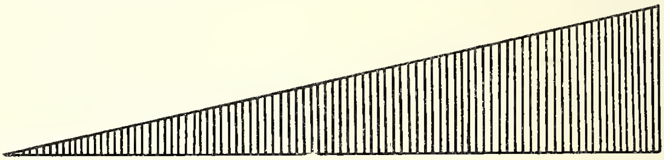


Fig. 130.

screen; (3) a magnifier arranged so that the eye cannot accommodate itself to objects not in the focal plane.

(1) In order to test whether the plate occupies exactly the same position as the screen on which the image was focussed, a wedge-shaped piece of stout cardboard is cut out and ruled as shown in fig. 130. A steel rule or other thin rigid surface is laid across the frame of the focussing screen and the wedge introduced between it and the glass. The line coming against the edge of the rule is noted, and on a similar test being made with a plate in the dark slide, the rule being laid across the front of the slide, the same mark should register against the edge of the rule.

(2) Ground glass is too coarse for the finest focussing. In place of it we can use some other obscuring medium of finer grain or a piece of plain glass with fine lines ruled on it. For obscuring glass hydrofluoric acid gas gives a very fine grain indeed and is permanent, but it is a dangerous material, and we recommend it only to those familiar with it. A more convenient medium is an emulsion of barium sulphate in gelatine, as recommended by W. K. Burton.

A piece of clear glass, without any obscuration whatever, enables the image to be focussed with a magnifier (see below) if it bears a few fine black lines. These may be scratched with a diamond, or some hairs may be cemented under a thin film of Canada balsam to a piece of ground glass. The glass surface simply serves as a plane in which the focussing magnifier can be moved about parallel to the plane of the image. The lines on the glass must appear sharply focussed whenever an observation is being made : their purpose is to prevent the eye accommodating itself to perceive as sharp the aerial image which is not in the true focal plane. It is not sufficient merely to adjust the focussing magnifier once and for all and to disregard this accommodation : a line which can be sharply focussed, and is known to lie in the focal plane, must lie alongside the image at the time of focussing. For ordinary field and interior work the high quality of a focussing magnifier is not important, and the instruments which are sold at from 2s. 6d. to 10s. 6d. each are quite sufficient. Indeed a cheap shilling microscope as sold at the toy shops serves this purpose quite well. But for accurate and critical focussing an achromatic and anastigmatic eye-piece is essential. That made by Zeiss is sold for about 25s., and is a tool which in scientific work is worth what it costs.

[4] *Pictorial Focussing and Diffusion of Focus.*—It would be easy to fill a book with what has been said about the badness of sharp pictures and the goodness of unsharp ones, or *vice versa.* Much of this is a matter of taste, and before telling how to obtain unsharp pictures we make room for a quotation from George Davison which states the case for the "fuzzy" picture.

Writing in *The American Amateur Photographer*, Mr. Davison says :—

"To me sharpness everywhere almost invariably tends to a fiddling, prosaic effect. It may be *natural* in its appearance as much as any other method of focussing, but where pictorial qualities are concerned it seems the weakest, most disturbing and confusing style of treatment. On the other hand, with differentiation and diffusion, even without any other qualities, an effect in pictorial representation is given more broadly, with greater force and directness, than when there is a detailed enumeration of all the minute facts equal in emphasis with the main effect selected by the seeing eye of the artist."

[5] *Getting "Diffusion of Definition,"*—which is what is meant when "diffusion of focus" is mentioned. There are several methods

by which the definition of a lens can be broken up to a greater or less extent. Pinholes and spectacle lenses of course will give the same effect, but they do not come under consideration here.

One of the crudest methods is vibrating the camera at hte time of exposure. This is a practice with which one of the most eccentric of the new school of photographers was credited with using extensively. A gentle vibration was imparted to the tripod by suspending a heavy weight to the head by a cord, and drawing a violin bow across the cord at the moment of exposure.

Racking the lens slightly during exposure was made use of by Claudet for large portrait work. The lens was first focussed on some feature of the face, and during exposure a turn was given to the pinion so as to remove this feature out of the focus and to bring others into focus, the result being an equally diffused definition.

Another simple dodge consists in holding a spirit lamp below and in front of the lens hood, the stream of rarefied air thereby produced throwing the image slightly out of focus. This process was patented by a New York photographer, who christened the portraits taken by it "vibrotypes." Soft definition due to the introduction of spherical aberration can be obtained *by opening out the aperture* of the lens. The single lens is practically the only one the diaphragm of which can be thus treated, and the method possesses the disadvantage that softness can only be obtained simultaneously with the use of a large stop. For many purposes it is a convenience to introduce spherical aberration when using a small stop, a power which is given by a special symmetrical lens of Dallmeyer. (See the Dallmeyer Bergheim Lens, Chapter XI.) The extent of enlargement of aperture which a lens will stand can be found only by trial. The best way is to have the aperture enlarged rather more than sufficient, and to then find by experiment with various paper or cardboard apertures the most suitable sized diaphragm to employ. W. J. Stillman made a note a few years ago of the roundness and artistic quality of definition given by a lens when used at a larger aperture than that intended by the makers. His remarks referred to the concentric lens used at f12. He focussed at f22, and on opening out the diaphragm to f12 found that the details were surrounded by a kind of faint halation, and, although there was good definition, a pleasing soft effect was obtained.

The use of a large aperture during part of the period of exposure has long been recommended as a means of reducing exposure in interior work, but, as recently pointed out by G. A. T. Middleton, this procedure gives a softness of focus from the blending of the

sharp and unsharp images, and allows the photographer scope for the exercise of his artistic faculty in representing distance. To take advantage of the device in landscape work, it is necessary to use slow plates.

Another method is due to C. Whitney, and was described some years back in the *British Journal Almanac*. In place of the ordinary diaphragms a series of cardboard ones are made ranging from *f*3 to about *f*16. On these are glued thick collodion films, having a central circular aperture equivalent to about *f*30. The thickness of the collodion is an important factor in determining the amount of diffusion obtainable. For a soft pleasing effect, use a cardboard diaphragm of *f*16 in conjunction with an aperture in the collodion of *f*30; for increased diffusion the same size of aperture in the collodion is used in conjunction with an aperture in the cardboard of *f*12 or *f*8. A variant of this latter plan is that suggested by Bigelow and used by Baron A. Rothschild. In place of the diaphragm a piece of plain glass is inserted upon which circles have been scratched with a diamond.

[6] *Focussing by Scale.*—The equations for conjugate foci enable the gradations for the focussing scale to be calculated, but it is necessary to know the equivalent focal length of the lens with very great accuracy. It is much better to graduate the scale by practical trial, focussing sharply, by aid of a magnifier, on a test object at various distances.

CHAPTER XIV.

THE LENS AND THE CAMERA.

[1] *The cleanliness of the lens* is a very important point, for if the surfaces are covered with dust the lens scatters light uniformly all over the plate, thus giving flat and fogged-looking negatives. This is a frequent cause of failure in hand-camera work. The lens cannot be got at for cleaning; it accumulates a film of dust and the result is a succession of fogged plates. Let the reader bear in mind that just as the ground glass diffuses light in all directions, and is therefore used behind a negative which is to be enlarged, so a lens covered with dust particles scatters part of the light which reaches it. Dust on the lens is seen at once if the lens be pointed to the sun or to the flame of a lamp. To remove dust, see Chapter XVI.

[2] *Reflected Light in the Camera.*—Another cause of flat negatives is the light reflected from the sides of the camera on to the plate. This is most likely to happen when a lens is being used which covers a plate of larger size than that carried by the camera. Light falls on the folds of the bellows and is reflected and re-reflected on to the plate. The first thing is to have all wood and metal inside the camera an absolute dead black. Pay special attention to the deep woodwork close to the focussing screen found in some cameras. An improperly blacked framework has been known to cause a band of fog across one end of the plate.

But in addition it is sometimes necessary to cut down the cone of rays transmitted by the lens, so that the sides of the bellows are unilluminated. This may be done by a diaphragm outside the camera, or one or more diaphragms inside. The former is better, though the latter is on the whole more convenient. To fit up an interior diaphragm, see *The Photogram*, March 1901, p. 80.

The exterior diaphragm is more difficult to arrange. As Chapman Jones writes in *Camera Obscura*:—"What is wanted is a second front to the camera to project an inch or two beyond the lens with an

opening of the same proportions as the plate, adjustable towards and from the camera and also up and down, to allow for the rising front. It should be connected to, or connectable with, the camera front, the space between being covered with a very light bellows or a simple flexible material, to exclude light." Though difficult of application to a stand camera, a rigid hood might very well be fixed to many hand cameras.

[3] *Rising Front or Swing Back in relation to the Lens.*—When a building appears too low down on the plate, as in fig. 137, the best thing to do is to first raise the front of the camera as far as it will go. When by this means the view has been correctly placed, we have still to see whether the bottom of plate is being properly covered by the lens. With most modern anastigmats there is a reserve of covering power sufficient to exhaust the rise of front on most cameras. But with an older lens it often happens that the lower part of the plate is not covered sharply. The lens will not cover a much greater field than the circle enclosing the plate, and by raising the front we have lifted this field of good definition above the lower part of the plate (fig. 133). Now we can still obtain a sharp picture all over the plate if the front of the camera will swing. By tilting the lens upwards we do two things at the same time. We raise the view on the plate and we depress the field of definition so that once more the bottom of our plate is covered (fig. 134). To get this result we have turned the axis of the lens through a certain angle. It is no longer at right angles to the plate. Hence we shall find that to secure perfectly sharp definition over the whole plate, we have to stop down the lens considerably.

We have been supposing that the camera has been set level before the view and the lens front has been raised, but very often it is not possible to include what we want by the use of rising front alone.

[4] *Distortion from Tilting.*—Then we must tilt the camera. As soon as we move the plate out of the vertical (when viewed edgeways), we begin to introduce distortion of the kind shown in fig. 131. The figure shows the result of tilting the camera upwards. Tilting downwards, as when photographing from a window, produces distortion of the opposite kind, the properly vertical lines in the picture appearing to converge towards a point below. To get rid of this distortion the plate must be swung backwards or forwards, as is necessary, until it is exactly upright when viewed edgeways. To test whether this is the case it is well to have a plumb line or rod attached to the side of the camera or to have a spirit-level set in the top.

Now a minute's thought will show us that tilting the camera and swinging the back are together a roundabout way of raising the front, with this difference, that in the first case the axis of the lens is

FIG. 131.

thrown out at an angle to the plate, unless the front of the camera is also swung. Figs. 135 and 136 will make this clear.

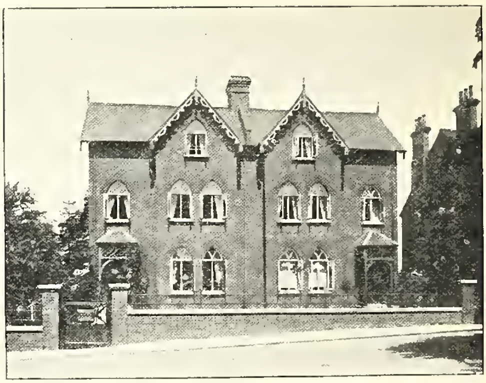


FIG. 132.

[5] *Rising Front and Swing Front.*—The gist of all this in practice is that it is best to make the adjustments with the rising front alone; or, if this is not possible, with the swing back and swing

front. If a swing front is not fitted to the camera, the lens must be stopped down to $f22$ or $f32$ in order to get all parts of the image into focus.

[6] *The Swing Back* is made in two patterns. In one, principally found in cameras of heavier design, such as Watson's "Premier," the back swings from its centre. In the other pattern it is hinged to the camera baseboard. The first type is the best when there is no

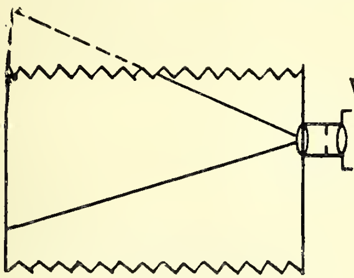


Fig. 133.

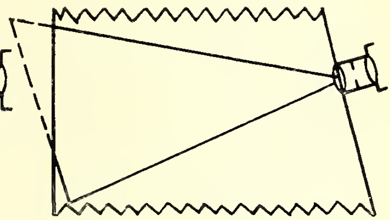


Fig. 134.

swing front on the camera, because the movement of the plate in regard to the lens is *nil* at the centre of the plate and equal but opposite at the top and bottom. Hence one has only to focus at the centre of the plate and stop down, and one gets the best definition all

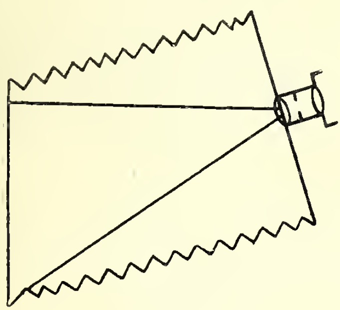


Fig. 135.

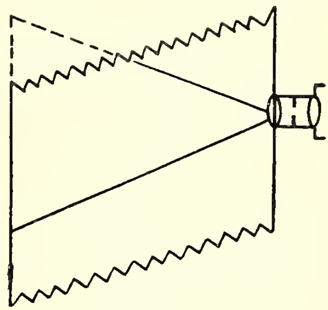


Fig. 136.

over the plate possible with that particular stop. On the other hand, the hinge-like swing of the more usual form is all in one direction, but the top of the plate moves much nearer the camera than the middle portion. Both patterns equally correct distortion, but with the hinge swing the operator can focus only by trial, and is in the dark as to whether he is getting the best from his lens.

Moral and practical advice :—

(1) Use the rising front to the full before tilting the camera. Most cameras unfortunately could do with greater range of this movement. Figs. 137 and 138 were made from exactly the same standpoint, the only difference being the position of the lens board. This was with a Sanderson camera, and it should be added that the actual rise possible with the instrument is much greater than that shown here. But very few cameras could have produced the result here shown.

(2) If, with great rise, the base of your plate is not covered, tilt the lens upward.

(3) If the rising front does not suffice, tilt the camera and swing

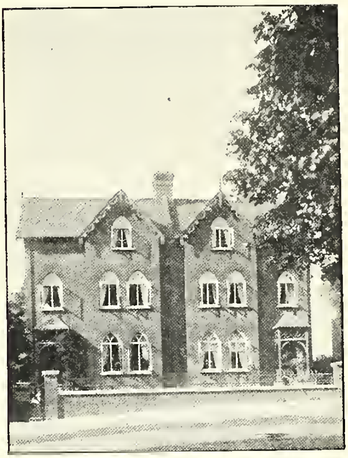


Fig. 137.

Fig. 138.

the back into a vertical (edgeways) position and stop down the lens. You may swing the front vertical also: the gain is the power to use a larger stop; the loss a lower position of the picture on the plate.

[7] *Swing Back and Round Fields.*—In the above diagrams we have regarded the field of the lens as flat, and so it is in the case of most modern anastigmats. But many older R.R's. and landscape lenses have very round saucer-like fields, and in such cases the swinging of the back of the camera becomes more complicated.

It would serve no useful purpose to elaborate directions as to how to use these lenses. The worker who wants critically sharp pictures will get a flat-field anastigmat: the artist-man will learn to

use his curved field lens by watching the focussing screen. And this brings us to a practical point.

The swing back often helps us to work with a larger stop and still get all planes in focus. Take an example: a river landscape with a foreground of rushes. We know that to get them in focus we must rack out a little further. Instead of this we can swing back the plate a little, and thus get foreground and distance in focus with the same large aperture.

[8] *Rectifying Distortion.*—Even if the plate was not vertical when exposure was made the picture is not lost. The distortion can be corrected by copying. Many formulæ and calculations have been published providing for the degree of tilt requisite when making the subsequent copy. But that is a cumbrous method, and we prefer to recommend the reader to follow the plain directions sent us by Professor F. J. Allen, M.A., M.D., on our happening to mention to him that this book was in progress:—

"No good subject need be rejected merely because it cannot be taken with an upright camera back. It may be taken with a tilted camera, and a rectified copy may be made from the negative. In fact, some subjects are better treated this way, because it admits of more perfect definition than is possible when the swing back is used in the ordinary way.

"A rectified positive is first taken from the negative in a camera. For this purpose I recommend a departure from the usual instruction 'to put the negative upright, and swing the camera back so far as to get an upright image,' for by this means only a limited portion of the image can be correctly focussed. A much better general definition is obtained by slanting the swing back *and the negative* to the same angle but in opposite directions, thus:—

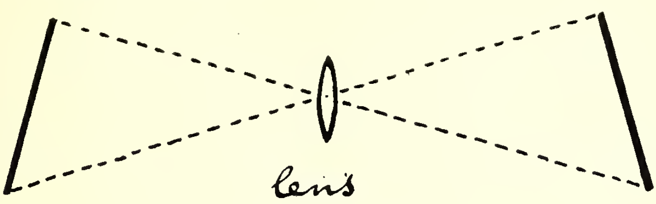


FIG. 139.

"It might be supposed that some disproportion would be produced by this method; but I have tried it with a geometrical figure, and

found that the proportions of the copied negative do not differ materially from those of the original figure.

"In rectification it is desirable to use a short focus lens; for the shorter the focus, the less will the plates have to be slanted. To rectify a whole-plate I use a $7\frac{1}{2}$-inch lens: a 5-inch lens is suitable for a 5×4 plate.

"If the perspective be too pronounced to be fully corrected in the positive, the operation may be divided into two stages, a partly corrected positive being first made, from which a fully corrected negative is made in a similar manner.

"I say 'fully corrected,' but I recommend that in architectural pictures a slight upward convergence of lines be allowed. If they be bolt upright, the effect is evidently contrary to experience, and the lines are apt to appear to splay outwards.

"When the positive is a rectified one, the negative càn be printed from it by contact.

"Positives and copied negatives should be made on the slowest available plates, as the faster plates are too coarse in grain.

"It should be remembered that copying in the camera softens the grain of the image, whereas printing by contact accentuates it, especially when the source of light is a naked flame.

"The best kind of positive for reproducing purposes is one which is too heavy for pictorial effect—over-exposed but fully developed, with pronounced detail in the high-lights, and little or no clear glass. A brilliant positive is unsuitable: it makes a negative in which the lighter parts of the subject are flat and detailless.

"In reproducing negatives the gradation can be modified at will, long development increasing contrast and short development diminishing it. But whatever the development, the exposure must never be deficient.

"It is almost unnecessary to say that in copying, the size of the negative may be enlarged or diminished.

"It is a great convenience, when copying in the camera, to take the picture on a plate a size larger than itself. This saves much time and trouble in centring the image, and the possible disappointment of finding that after all an important part of the margin has been omitted."

CHAPTER XV.

COPYING. ENLARGING. PROJECTION.

[1] *Optical Rule in Copying.*—When a drawing or other picture has to be copied, the lens must be further from the plate than when photographing a distant landscape. The reason of this is given in [6], Chapter I.; see also "Conjugate Foci," Chapter II. The distances of the lens from the plate and from the object follow a definite rule, which is repeated here from Chapter II. in the form best adapted for practical work. The first thing is to know the focal length of your lens. The next is how much smaller the copy is to be than the original. This latter point must refer to the relative lengths of the copy and the original, not to their areas. Suppose our lens is 6 ins. focus and we are going to copy a drawing 12 ins. broad, so as to get a copy 4 ins. broad. Required to know how far away we shall place the camera and to what length extend the bellows. Divide the breadth of the original by the breadth of the copy. 12 divided by 4 is 3. This figure, 3, is the "reduction." Now here is our rule.

Divide the focal length of the lens by the "reduction" figure and add one focal length thereto. This gives the camera extension. Thus $6 \div 3 + 6 = 8$.

Multiply the focus by the reduction factor and as before add one focal length thereto. This gives the distance from lens to copy. Thus $6 \times 3 + 6 = 24$.

A useful check on the calculation is to notice that the distance from lens to object must be the same number of times greater than the distance from lens to plate as the size of original is larger than the size of the picture on the plate. Thus in our example $24 \div 8 = 3$ and $12 \div 4 = 3$.

Now it will be asked where in the lens mount must these distances be measured from. For exact work one distance must be measured from one point and one from another—the nodal or Gauss points of

the lens (see Chapter II.). For "near enough" work measure from either surface of a single lens or the stop of a R.R. and focus.

[2] *Copying with Short Extension Camera.*—It often happens that the camera will not rack out far enough to copy on a large scale. Copying same size demands an extension twice the focus of the lens. This can be got over without resorting to a lengthening tube. By placing another lens in front of that on the camera the focal length of the whole is very greatly shortened. Copies as large and larger than the original can be made. One useful application of this is in making enlargements of single figures from groups. See *The Photogram*, 1894, p. 301.

[3] *Camera for Copying.*—The camera for copying work should rack out from the back—*i.e.* the plate should move, not the lens. There are optical reasons for this. See T. Perkins, *The Photogram*, 1899, p. 301.

Enlarging.

[4] *Enlarging* is copying with a difference—the difference being that we bring the lens nearer to the original (*i.e.* the negative) than to the sensitive surface. We have passed the point of copying same size, and as we move the lens nearer to the negative, and the focussing screen further away behind it, we get greater and greater enlargement. Usually it is convenient when the apparatus is used in this way to turn the lens round so that its hood faces the plate.

Precisely the same simple rule of distances given above holds good when enlarging, only that it is applied somewhat differently. An example will make things clear. With a 6-inch lens we want to enlarge a quarter-plate (4 ins. in length) to 12×10 (12 ins. in length). Required:—distances from paper to lens and from lens to negative. A moment's consideration will tell us that the first of these two is the greater, and that in place of a "reduction" number we have an "enlargement" number. We use it in the same way, however.

To find distance from lens to paper, $6 \times 3 + 6 = 18$.

To find distance from lens to negative, $6 \div 3 + 6 = 8$.

Exactly the same figures as before, but their positions interchanged.

We may repeat the general rule.

To find distance (1) from paper to lens, (2) from lens to negative when enlarging. Multiply focal length of the lens by degree of enlargement and add one focal length. This gives distance from paper to lens.

Divide focal length by degree of enlargement and add one focal length. This gives distance from lens to negative.

The above is really all the optics of enlargement pure and simple, but we must go on to note some points of practical importance which come under the head of the—

[5] *Optics of the Enlarging Lantern.*—When enlargements are made by artificial light it is necessary to use a lens between the negative and

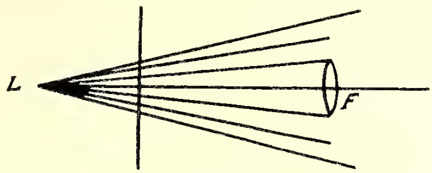


Fig. 140.

the light. Fig. 140 shows why this is so. The rays from the source of light spread out in all directions and only a very small proportion find their way through the lens. By inserting a converging lens behind the negative the whole bundle of rays is drawn together and transmitted through the negative to the lens as shown in fig. 141. A lens used thus is called a condenser, and in practical enlarging it is important to understand its action.

[6] *The Condenser.*—The nearer the light can be brought to the condenser, the better, of course, the illumination of the negative. But there is a limit to the converging properties of the condenser, and

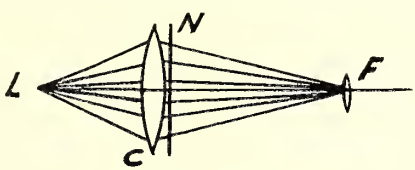


Fig. 141.

when rays over a very wide angle fall upon it they are not rendered convergent. For this reason the single lens cannot be used as a condenser. The double and triple forms of condenser are the only practicable ones. The latter are especially necessary in the larger sizes. Fig. 142 shows a triple condenser designed by J. Traill Taylor, in which the condensing action takes place in three stages. The small meniscus lens intercepts the outer rays of the beam from the light, L, and transmits them as a less diverging beam to the second lens, from which they emerge parallel, to be brought to a focus by the third

element. With a condensing lens of this type rays including an angle of 90° can be intercepted and transmitted to the negative.

The condenser has two conjugate foci just like any other lens. If the light is removed further away the focus approaches the condenser. On the other hand, the nearer the light, the further away the focus on the other side of the lens.

The position of the negative between N and F (fig. 141) decides the brightness of the enlarged image, because all the light emerging from the condenser is collected at F. Therefore the nearer we place the negative to F the brighter the image and the shorter the exposure required. The size of the cone of the rays gradually diminishes from N and F, and usually in a bought enlarging lantern the negative for which it is listed must be placed fairly close to N.

[7] *Two-fold object of Condenser.*—The condenser thus performs two distinct duties: it intercepts light which would otherwise never

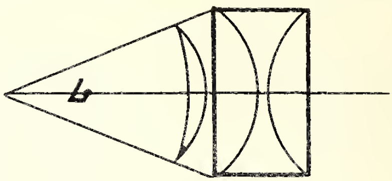


FIG. 142.

reach the negative, and it concentrates the bundle of rays which fall on it into the cone-like section seen in fig. 141. Were the source of light a minute bright point and the condenser free from aberration, it would produce the enlargement without any projection lens. As it is, the cone of rays does not taper off absolutely to a point but has an appreciable area in its thinnest cross-section: it cannot produce an image approaching sharpness. A fine pinhole would enable us to cut down the rays which cause unsharpness and produce an almost sharp picture. By using a lens instead we do the same thing and get much greater rapidity.

[8] *The proper position for the objective* is at the apex of the cone of rays from the condenser, F, in fig. 141. Obviously if placed away from this point in either direction it would cut out a certain portion of the bundle of rays, thus causing loss of illumination. Therefore in fitting up an enlarging lantern the first consideration should be the adjustment of the condenser and objective in this way.

With a good condenser and light of small area, large aperture in the objective is not of great importance, because the cone of rays is brought

to a fairly fine focus. But when the cone of rays is broader, a lens which can allow them all to pass is the best, say a portrait lens working at *f*4.

[9] *The Stop in Enlarging.*—As will be anticipated from the last paragraph, the stopping down of the objective used in conjunction with a small light like the electric arc and a properly arranged condenser makes no difference until quite a small aperture is reached. This fact is liable to lead to difficulties which at first sight seem inexplicable : as, for example, the following from the proceedings of a London Society :—In using an enlarging lantern fitted with arc-light condenser and high class objective, exposure was purposely lengthened by introducing first a piece of yellow glass between the light and the condenser, and secondly a piece of ground glass. Results : in first case, still excellent definition ; in second, very inferior definition. The reason, of course, lay in the diffusive action of the ground glass which sent forward through the condenser a cone of rays no longer tapering to a fine point but to a disc which covered the whole area of the lens.

CHAPTER XVI.

PRACTICAL MISCELLANEA.

[1] *Care of Lenses. Lens Cases.*—A lens should be as free as possible from dust or film of grease, either of which scatter light into the camera and cause foggy images. Care should be taken as to how the surfaces are cleaned, for many of the modern lenses are made of comparatively soft glass which is easily scratched. The chamois leather of the bag in which the lens is often carried is by no means the best thing for the purpose. Better is a piece of old silk or muslin that has been washed and re-washed until it has become very soft. According to Dr. Miethe, the best material for cleaning the edges of mounted lenses, at which it is difficult to get with a cloth, is pith, especially the pith of the rush, sunflower, or elder.

If a lens shows a dirty mark which cannot be removed by rubbing merely with a dry cloth, a drop of alcohol may be applied, and at once rubbed off again. Water, ammonia, or any such chemicals as are usually used for cleaning should on no account be used. According to Chapman Jones, the best receptacles for lenses are flat-sided rectangular boxes made of brown paper, the ends being folded and glued, and a flap from each of the two sides and ends left to fold over and close the top. They are easily made of any size, and when worn or damaged are repaired by gluing another piece of brown paper outside the original. They keep out dust excellently, and if let fall, will rarely strike the ground on other than one corner, which, of course, is not in contact with the lens.

Lenses should always be kept in cases at home as well as in the field. Light is apt to develop yellowness in some glasses; and air, damp, and dust combine to affect the polish of the glass surfaces.

[2] *Screwing and Unscrewing.*—There is a right and wrong way of fitting a lens into its flange. The right way is to first turn the tube backwards—*i.e.* the wrong way of the thread—until the two click at

the point where the threads meet. Then reverse the movement, and the lens will enter its flange quite evenly. A lens can be fitted into a larger flange than the one in which it properly fits by wrapping a bit of soft paper, or tape, or a strip of pocket handkerchief around the lens-thread. In emergencies this plan is useful. For experimental work at home with lenses an extra sliding board (to the camera front) of thick cardboard, in which a circular hole a shade smaller than the lens flange has been cut, forms the readiest means of fixing the lens. The lens is inserted with a circular motion and a thread is thereby cut in the cardboard.

If a lens sticks in its tube or flange, do not use pincers or vice. Take a piece of tape, make a turn about the part to be unscrewed, and pull the remaining end in the direction for unscrewing; if not successful, apply moderate heat from a spirit lamp flame to the part of the screw, and give a motion to the part containing the lens, contrary to that simultaneously given to the body of the objective from which you wish to separate it.

[3] "*Starring*" *Balsam, Un-cementing and Re-cementing.*—In old lenses a peculiar star-like condition of the balsam is apt to appear. The only remedy is to separate the glasses and re-cement.

To un-cement a lens, remove from the metal mount and place in some warm water (contained in a saucepan on the bottom of which a few thicknesses of blotting paper or flannel have been laid). Add hot water gradually until at last the whole is too hot for the hand to bear any length of time. When this is the case, quickly apply a twisting movement to the upper lens, holding the lower one. They should slide apart. If they do not, the only thing is to make hotter and try again. When separated, they should be thoroughly cleaned with benzene or turpentine before being re-cemented.

To re-cement, place the lenses on several thicknesses of rag or blotting paper in a fairly hot oven until thoroughly warm. Likewise place a little Canada balsam alongside until it is thoroughly fluid. Then drop just one drop in the centre of the concave lens and very gently lower the concave surface of the other into contact. Press slowly together, allowing the excess of balsam to exude from the sides. Let stand in the warm for a few minutes, again press and note if any more balsam escapes; if none, place aside to cool, and remove the balsam adhering to the edges with a rag just moistened with alcohol and benzene. If any difficulty is met with in getting the balsam to become fluid, a little benzene may be added and the two thoroughly mixed in the warm—*i.e.* by placing the bottle containing

the mixture in a saucepan of hot water and mixing by an occasional rotatory movement.

[4] *The Lens Mount. Lacquering. Removing Lacquer. Blacking Stops, etc.*—Laequering is a special process beyond the average worker. An excellent substitute, however, for a lacquer is celluloid varnish (celluloid in acetone or amyl acetate), which, applied to brass cold, gives a tough transparent coating: it requires an hour or two to dry.

To remove lacquer from brass rub the surface with a tuft of cotton-wool dipped in a mixture of equal parts of alcohol and ammonia.

Blacking stops and the interior of the lens mount is a point that should occasionally be looked to. The best black varnish for parts which are not to stand much rubbing is made from shellac solution, turpentine and *vegetable* black. It is not possible to give a formula. The proportions should be adjusted until the best result is obtained. Use strong shellac solution as used by French-polishers, thinned if necessary with a little methylated spirit. The black should be in as fine a state of division as possible. In making the mixture put a few shot in the bottle and shake vigorously: this ensures freedom from lumps.

CHAPTER XVII.

TESTING LENSES.

PRELIMINARY TO PHOTOGRAPHIC TESTS.

[1] *Focal Length and Nodal Points.*—In Chapter II. it is shown that the focal length of a lens is the distance from the focal plane to a certain point—the node of emergence: which point may be in, or before, or behind a single lens, and may occupy almost any position in the case of doublet lenses. Hence any method of determining focal length which directs measurement to the lens or to the stop is unreliable: the result may be practically correct in many cases, but altogether wide of the mark in others. For example, by focussing on a distant object and measuring from the surface of the lens to the ground glass, one would obtain, when working with the back combination of a 6·4-inch stigmatic, a focal length $1\frac{1}{4}$ inch too long (see fig. 26). To be practically useful a method of determining focal length must not involve any knowledge of the space between the nodal points or the position of the latter. Of the many methods recommended we will give here only a few which are of practical usefulness either for (1) the ordinary man who wants to find the focal length of his lens with as little trouble as possible and with as simple apparatus; (2) the man who wants to determine the focal lengths of a number of lenses as rapidly as possible consistent with accuracy; and (3) the worker who wishes to make his determination with the greatest possible accuracy independently of time, apparatus, or calculation.

[2] *Focal Length by Grubb's Method.*—Recommended to people of class (1). Requisites:—Camera of ordinary extension; lidless box on which to fix camera; level board on which is pinned sheet of white paper. If the camera is fairly heavy, has a baseboard with a straight side, and will stand steadily on the board, the box can be dispensed with; otherwise it is necessary to screw camera to the box, the shape of which does not matter so long as it stands firm and has one side giving a sharp straight edge on the paper. Make

a thin vertical pencil mark on the focussing screen, each about half an inch or so from opposite edges of the screen. Focus on a distant object, say a factory chimney or the side of a house, so that some vertical line falls exactly on one of the pencil lines. Make a mark along one side of the camera baseboard (or the edge of the box) on the paper, and procced to shift the camera until the same line in the landscape coincides with the second line on the screen. Again make a line on the paper, using the same guiding edge. We have now all the data for getting the focal length, and must remove the paper and carefully complete the drawing.

At this stage we have only the two lines A B and A C (fig. 144). We first measure with a pair of dividers the distance between the

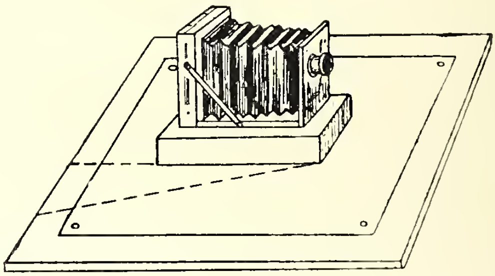


FIG. 143.

two marks on the ground glass and carefully press the points of the dividers on to a line L M drawn on the paper. We want the half of L M, and obtain this by the method a draughtsman always uses. A first trial with the dividers gives, say, the point N. We set off P by placing one of the points of the dividers at M. It is now easy to extend the dividers slightly so as to accurately get the middle point of N P, which is also the middle point of L M (fig. 145).

This done, we next bisect the angle B A C. Placing the pointer of the dividers at A we mark off any convenient distance along A B and A C (*a* and *b*), and then from *a* and *b* draw two small arcs of circles which cross at *c*. By joining *c* and A, we bisect the angle B A C. Now we want to fit in the half length, L Q, between the lines A *c* and A B and at right angles to A B. The easiest way to do this is to set the T-square along A *c* and to move a set square along it until, on testing with dividers extended to the length L Q, the points fall on the lines A *c* and A B. Call the line so drawn D F. F A is the focal length of the lens ; it is

measured by spanning with a pair of dividers, and applying the latter to a scale.

If this construction be done carefully the results by this process are very accurate. All the lines should be drawn as fine as possible, the dis-

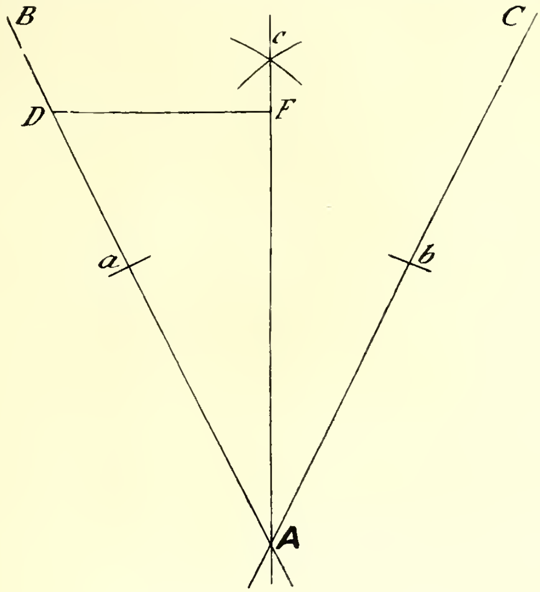


Fig. 144.

tance between the lines on the ground glass should be as great as possible, and a delicate pair of dividers and accurate scale should be employed.

[3] *Focal Length by Schroeder's Method as modified by Chapman*

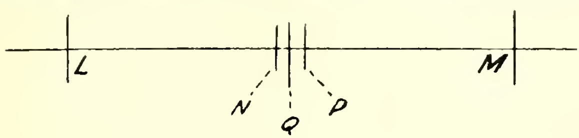


Fig. 145.

Jones.—Schroeder's method is to focus on a distant object and then on a scale, making the image of the latter the same size as the original; the distance through which the lens (or plate) must be moved from one position to the other is the focal length. Mr. Chapman Jones' modification consists in dispensing with the full size accurate reproduction of the original in the second operation, a smaller image being

carefully measured and the necessary correction made. The following practical directions are quoted from Mr. Chapman Jones (*Camera Obscura*):—"First, focus sharply a distant object, so distant that it is equivalent to an infinite distance. If it is a thousand focal lengths away, the error in position of the focussing screen will be the one thousandth of one focal length. Such a fraction will probably be negligible in a 10-inch lens or one of smaller focal length. Mark the position of the movable part of the camera, either back or front, by a fine mark on the baseboard. Next, make two crosses with the fine point of a hard lead pencil on the focussing screen exactly ten centimetres apart (this is convenient for a half-plate camera), using preferably an engine divided paper scale such as are now in common use. Rack out the camera to approximately twice the focal length of the lens, or, if it will not allow of this, as far as convenient. Then sharply focus the scale so that the image of its gradations lie over the two marks already made, and read off on the focussing screen how many divisions of the scale are included between the two marks; call this m. Mark the baseboard as before and measure the distance between the two marks; call this f. If m is equal to ten centimetres, f is the focal length, as in Schroeder's method. In any case, f multiplied by m and divided by 10 will give the focal length. The ten centimetres is a convenient distance to take for half-plate cameras, but obviously it may be any other known distance. . . . The accuracy of the estimation depends solely on the worker himself, and is simply a matter of good critical focussing and the measurement with a scale from one mark to another. The results of two estimations, at different times, with the same lens, will probably not vary more than the fiftieth of an inch, or even less if the focussing is critically done and the measurements are made with ordinary care."

[4] *Focal length by comparison with a standard lens* is the best method for those who have a large number of tests to make. It depends on the fact that the size of the image is proportional to the focal length of the lens. A lens of accurately known focal length is focussed on a well lighted object at a fixed distance from the lens (*e.g.* two black lines on a white wall). The camera is fixed and arranged to rack from the back so that when the lens is replaced by the one to be tested the only difference is the focal extension of the camera. A simple rule of three sum gives the focal length of the lens:

$$F = \frac{\text{Focal length of standard lens} \times \text{length of image No. 2}}{\text{length of image No. 1}}.$$

[5] *Focal Length* (*Dallmeyer*).—Focus the lens on a very distant

object and mark the position on the baseboard (fig. 146). Next reverse the lens in its flange and again focus on the same distant object, this time measuring from some fixed point on the lens, say the hood (fig. 147).

Now replace the lens in its normal position with the screen at F_1,

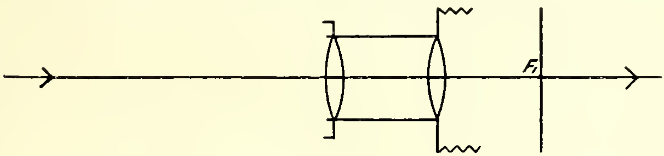


FIG. 146.

and remove it an exact distance (y) further away, roughly about one fourth of its distance from the lens for convenience (fig. 148). Lastly, find the distance now necessary for the placing of an object O so that its image is well defined at the new position of the screen at I.

$$F = \sqrt{xy}$$

i.e. we must multiply x y and extract the square root of the product.

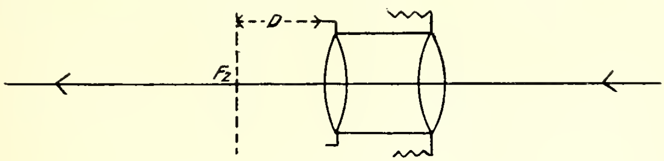


FIG. 147.

[6] *Focal Length* (*Dallmeyer*).—The method described by Mr. T. R. Dallmeyer (Traill Taylor Lecture, 1898) has the advantage that no measurements of the image nor from any part of the lens itself are necessary. The principle of the method is as follows :—In fig. 149

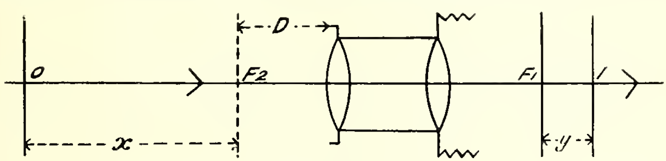


FIG. 148.

N_1 and N_2 are the nodal points of the lens which remains fixed throughout the test. An object, A, is sharply focussed and the position of the screen at A′ noted. Then A is moved a certain distance, l, to B, and again focussed at B′. It is again moved exactly the

same distance, l, to C, and again focussed at C′. Calling the distances A′ B′ and B′ C′, through which the focal plane is moved, c and a, the focal length, F, of the lens is given by the formula :—

$$F = \frac{\sqrt{2 \times l \times a \times c(a+c)}}{c-a}.$$

For proof of this formula see *The Photographic Journal*, 1898.

The focometer specially designed for use with this method has been presented by Mr. Dallmeyer to the Royal Photographic Society. It consists of a cast iron bench, 8 ft. long, graduated throughout its entire length into $\frac{1}{50}$ of an inch. Along this bench the various attach-

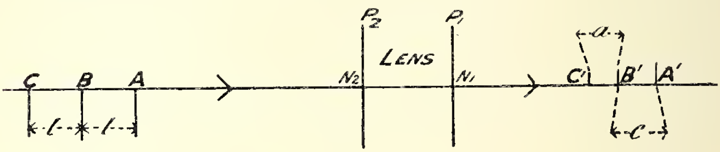


FIG. 149.

ments are moved—viz., a transparent scale (illuminated by a lamp) and a focussing screen, each with verniers attached reading to the $\frac{1}{1000}$ of an inch, by means of which the distances through which the fittings are moved can be accurately determined.

Between them, also moving along the bed, are two carriers which hold the lenses under examination. The second of these is only required when determining the focal length of a negative lens.

[7] *Finding Nodal Points.* — One well known property of the nodal point (of emergence) is that the image of an object at an infinite distance does not move when the lens is moved on a vertical axis which passes through this nodal point of emergence. This fact supplies a ready means for ascertaining the position of the nodal points; the nodal point of admission being found, of course, by reversing the lens. For experiments involving the use of a rotating lens a special apparatus is used by opticians. This is the tourniquet, and consists of a camera fitted so that the lens can be accurately turned about a vertical axis through any required angle. A simpler apparatus, which can be constructed at home, is that of Dr. R. S. Clay (*Photography*, 1901, p. 110), of which, since it lends itself also to the examination of lenses for the various observations, we give a brief description. A couple of pieces of board each with a V-shaped slot cut out are fixed to a small baseboard. They are placed so apart that the lens will lie upon them. Between the two boards a number

of holes are drilled exactly along the centre of the board and about a quarter of an inch apart. This baseboard is used on a second board on which a vertical pin is fixed, which passing through one of the holes in the lens-board, enables the latter to be rotated around a known point. In order, therefore, to find the nodal point we place the lens on the V's, fix up a screen behind it, and focus on a distant object, such as a chimney stack. We then try the effect of rotating the lens; most probably the image will move away across the screen; adjust the position of the lens over the axis of rotation by inserting the pivot in other holes, and finally (if a stationary image cannot be obtained with the holes alone) by shifting the lens a little on the V's. Focus the image sharply every time. The final position of the

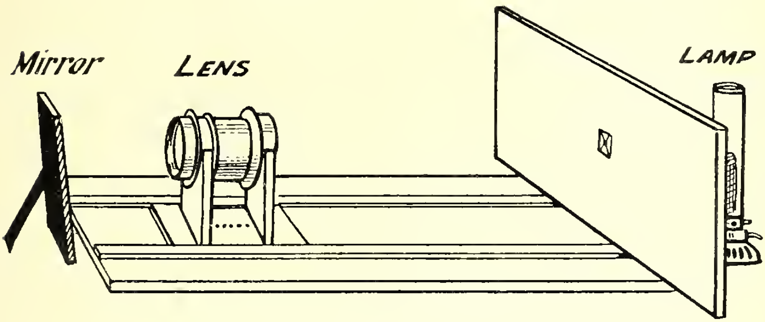


FIG. 150.

lens is such that the pivot is situated in the plane of emergence. The position therefore of the nodal point can be marked on the lens. The distance from pivot to screen is the focal length of the lens.

A more convenient method of working is warmly recommended by Dr. Clay. It enables the measurements to be made indoors by night and with far greater ease than when focussing is done in the ordinary way on a translucent screen. The principle is as follows:—When parallel rays of light fall on a lens they come to a point at the focus; on the other hand, if a point of light be placed at the focus, the rays from it will emerge from the lens parallel. If now a mirror be placed so that these parallel rays are reflected back through the lens, they will again converge at the focus. These facts enable us to dispense with our distant object. We make the lens itself supply the parallel rays, and we test the parallelism of these rays (reflected back by the

mirror) by observing that the point of light and its reflected image coincide.

"In practice," says Dr. Clay, "we do not use a point at *s*, but a small object. This can very conveniently be made from an unused dry plate. The film must be very neatly removed from an area about $\frac{3}{16}$ inch square, and a few sharp clean lines ruled on the clear glass in this area. These should consist of three horizontal ones, the same number of vertical ones, the diagonals and a circle. The gas flame (an incandescent for choice) is placed behind it; a piece of zinc with a similar hole is placed against the back of the plate to keep the light from the rest of the plate which is to act as the screen. The lines are on the film side of the plate and that side is towards the lens.

"The light coming through the hole in the screen must be arranged to pass through the lens and fall on the mirror, M. This must then be adjusted until the light is reflected back to pass again through the lens, and form a bright patch on the screen almost on the top of the ruling. This will be just a patch of light at first, but by moving the lens nearer or farther from the screen it will be brought to a sharp focus. This mirror must be adjusted until this image is almost overlapping the ruling itself—*i.e.* until it is just by the hole in the film.

"Lastly, the lens must be rotated on its pivot and adjusted as previously described until its rotation produces no motion of the image on the screen. When this is obtained, the distance from the point to the screen is the focal length of the lens."

[8] *Measuring Rapidity—i.e.* "*Working Aperture.*"—The methods of ascertaining the real focal aperture (or *f* No.) of a lens are dealt with in Chapter IX. on the diaphragm. Here we need only remind the beginner of the way in which the "focal aperture" is completely altered when one only of the components of a rectilinear is used. To find the real working aperture of the single lenses divide the focal length by the actual diameter of the stop. To confirm the focal apertures marked on the lens mount, divide the available aperture (which is a little greater than the real aperture, and is found as described in Chapter IV.) by the equivalent focal length.

Testing for Aberrations—Spherical Aberration, Astigmatism, Chromatism, Curvature of Field, Illumination of Field, etc.

[9] *Preliminary to any Photographic Tests.*—Before commencing any tests which involve the exposure of a plate, the worker should make quite sure that the surface of the sensitive plate occupies exactly

the same position as the surface of the screen on which the image is focussed; or, in other words, whether the slide "works to register."

Many lenses are unwittingly condemned as giving bad definition, when in reality the fault does not lie with the lens, but is due to a badly made dark slide. The simplest way of testing whether the slide works to register consists in taking a straight-edge or strip of flat wood and placing it so that it rests in the focussing screen frame (inside). Place now a wedge in the ground side of the screen and push it under the straight-edge. The point where the inclined plane of the wedge touches the straight-edge is carefully marked. This gives the distance that the glass is away from the top edge of the frame. A piece of glass is now placed in the dark slide and the shutter is withdrawn, the straight-edge is placed across the slide (as with the focussing screen), and the wedge is pushed under as before. Make a mark on the wedge as in the last instance. If the slide works to register the two marks should be coincident; if not, the slide is faulty. Very often the slide may be in register at one point and not at another—may be right for the centre and out at one end. If the slide is only a little faulty, a few strips of paper may be pasted on the rebate; that is, if the plate comes too near; if too far away, the paper should be pasted on the rebate of the focussing screen frame.

It is also necessary to be able to focus critically. See [3], Chapter XIII.

[10] *Spherical Aberration.*—As mentioned in Chapter IV. we test for spherical aberration by focussing rays from an object which pass through the centre of the lens and afterwards those coming through the margins. The image should be equally sharp in each case. To carry out the test, cut a disc of brown or black paper of about two thirds the diameter of the fixed stop of the lens: also a disc the full size of the lens with a central aperture a little larger than the small disc. Fix the small disc to the middle of the lens with a touch of gum, and focus sharply in the centre of the plate on a distant object—say a *Photogram* lens-testing chart placed so far away that its image is about one eighth the size of the original. Mark the position of the focussing screen or camera front, replace small disc by disc with circular aperture and again focus. With an aplanatic lens the two positions should coincide.

[11] *Astigmatism.*—To test for and measure astigmatism we focus on some object containing both horizontal and vertical lines and notice the distance through which the screen must be moved from the position of sharp focus of the horizontal lines to sharp focus of the vertical lines. This distance increases as the rays from the object fall upon

the screen with greater obliquity—*i.e.* the nearer the edges of the plate, the greater the astigmatism: in the centre of the field of the lens there is no astigmatism.

We have found a series of concentric circles drawn in good black Indian ink on a white card as good a test subject as any. Others use the cross bars of a window. J. H. Dallmeyer, Ltd., in their *Simple Guide to the Choice of a Photographic Lens*, give a special test object. Taylor, Taylor & Hobson issue concentric circle test cards.

[12] *Chromatism.*—Arrange a chart, such as *The Photogram* lens-testing chart, or simply a page of printed matter, some ten feet from the lens and inclined at an angle. Focus sharply with a magnifier at the middle of the chart and expose a plate (ordinary, not isochromatic). If any other portion of the chart is more sharply defined than the central focussed portion the chemical focus of the lens is not identical with the visual. This is not a precise expression of how the lens is working. The visual rays—those, it is generally assumed, by which the image is focussed—lie near the D line of the spectrum; those which usually form the photographic image on an ordinary plate between the lines G and F. For lenses which are to be used for tricolor photography, and in which, therefore, the highest degree of achromatism is desired, a much more stringent test is necessary. In this case red, green and blue filters are inserted in the optical system, and a lens of very high magnification being used in focussing the image, the difference in position for light of the different colors is noted. But here again it should be noted that unless the filter itself is extremely perfectly made, it may mask the performance of the lens. A filter placed on the lens hood or immediately behind the lens must have perfectly plane surfaces; otherwise it will upset the action of the lens, acting indeed as a weak supplementary lens. The nearer to the focal plane the filter is placed the less its action in this way can affect the performance of the lens, for which reason the best position of the light filter for lens testing (and also for actual work) is as close to the plate as possible.

[13] *Curvature of Field.*—Set up a test object, consisting of lines at an angle of 45° to the horizon—*e.g.* letter X. Unless this is a very considerable distance from the lens—say, one hundred times its focal length—it is necessary to have some means of guaranteeing that the lens occupies the same position, as each test is made through the angle over which it is supposed to cover. Therefore suspend a plumb-bob exactly over the diaphragm slit of the lens and mark the position of the back of the camera when the test object is focussed exactly in

the middle of the field. Now rotate the camera so that the image is an inch to one side of the centre, re-focus with the same point as before ; the back should occupy the same position as in the first case. In some lenses the fields of which are very curved, the back will have to be racked in a little to get the best definition. Mark the second position on the paper. It is important to remember that the lens must always be the same distance away from the copy. By moving the camera the position of the lens will be altered. The plumb-bob supplies a simple fixed point to work to, and it must be seen in all cases when focussing that the bob is above the same point as at starting. Focus inch by inch until the margin is reached, marking the position of the base at each time. When finished, draw on a piece of paper a perfectly straight line the length of the base of the plate, bisecting the centre. Next, one inch from the centre, erect a perpendicular equal to the distance that the camera had to be racked in when focussing for this position. Repeat for each inch. Next draw a line from the centre to the margin touching each of these perpendiculars. The result will be a curve representing the field of sharp focus for a flat object, and by comparison with the straight line judgment may be formed as to the quality of the lens in respect of flatness of field. If the field be very curved then a small stop should be used.

By working in this way with a plumb-bob, the test can be made indoors. The test object should of course be much smaller and finer in order to enable fine focussing to be done. As the image approaches the edges of the field it becomes more and more difficult to get the exact focus owing to astigmatism coming into play. For this reason the lines of the test object are made midway between horizontal and vertical.

[14] *Illumination of field* is not easily determined. For particulars of Sir Wm. Abney's methods as practised at Kew, see Major Darwin's paper (*Proc. Royal Soc.*, No. 318, p. 403).

[15] *Curvilinear distortion* is measured by the amount of sag between the ends of what should be a straight line. In order to test this a perfectly straight vertical line is focussed in the middle of the screen. A black plumb line against a white ground is the best test object. The camera is then turned on the tripod, so that the image of the line falls near the edge of the plate. We must now see how much the line is bowed out in the centre. To measure this "sag" the ground glass is put in, polished side next the lens, and a straight-edge laid against the points where the image of the plumb line cuts

the top and bottom edges of the focussing screen. On drawing a fine pencil line between these two points we can see how much (generally, how little) the distortion amounts to, and if necessary measure it.

[16] *Angle of Cone of Illumination, etc.*—The meanings of this term, of "angle of cone of illumination outside which the aperture begins to be eclipsed," are explained in Chapter III. To actually measure the angle requires a rather elaborate apparatus, but the following method is quite easy and needs only some after calculation. Focus on infinity; replace focussing screen by plain glass, on which mark centre, and with piece of card in which is a slit about $\frac{1}{16}$ of an inch in width, observe the gradual change in the form of the stop until it just commences to eclipse. Mark this point on glass. Do this either with a touch of ink or by pasting a horizontal strip of paper along the glass and drawing a vertical line on the card through the slit; the point occupied by the slit can thus be marked on the strip of paper with a pencil. Repeat the reading on the other side of the centre. The two readings ought to pretty well agree. Measure the distance between these points; it is the diameter of the circle which is the base of the cone of illumination outside which the diaphragm begins to eclipse. This is enough for practical purposes; but to get the angle itself divide the distance by 2 and then by the focal length of the lens. This gives us the trigonometrical ratio of the tangent of half the angle. Look up the angle corresponding to the number in a table and multiply it by 2.

A similar test, only moving slit until diaphragm entirely disappears, gives the angle of total illumination regardless of definition, etc. Similar calculation.

To find which stop gives angle which just does not eclipse stop, place slit at end or right in corner of plate and stop down until an unintercepted view of diaphragm is obtainable.

[17] *Defective centring* may be twofold. The optical axis of the lens may not coincide with the axis of the mounting tube, but this is of less importance than the axes of the separate lenses in a rectilinear not lying on the same straight line. Bad centring gives rise to defects similar to astigmatism or coma. To test, fix a brightly illuminated object fairly close to the lens and focus on it, arranging the camera level with the test object. Now turn the lens in its mount; if the image on the screen moves, the lens is not properly centred. It may be defective in either of the ways mentioned above. But now turn each of the lenses in the mount; if the image still moves, the axes of the two lenses are not in the same line.

A second and more delicate test is Wollaston's. A distant candle flame is examined through the lens held at arm's length. A number of reflected images will be seen which, if the lens is correctly centred, will fall into line one behind another as the lens is moved.

[18] *Flare spot* is not difficult to locate. Point the lens to a brightly lighted sky and watch the focussing screen as the lens is stopped down.

A more delicate method is that of Professor Miethe. On the inside of the ground glass fix a bit of black card (or, better, a tiny mirror) measuring about $1\frac{1}{2} \times 1\frac{3}{4}$ inch, so that the middle of the smaller side falls on the centre of the ground glass. Stop down the lens, and then looking sideways, in order to avoid blinding yourself, focus the sun on the screen close to the card or mirror. Then by slightly moving the camera get the image right on the card. The greater part of the light is absorbed, or in the case of the mirror is reflected out through the lens so that no diffused light is reflected on to the ground glass from the sides of the camera. One can now see a number of luminous circles arranged in a straight line and partly overlapping, the smallest being nearest to the centre of ground glass.

[19] *Color of the Glass, Surface, Bubbles.*—For rapidity, the glass of a lens should be as colorless as possible. To judge of the color lay the lenses on a piece of white paper in good daylight.

The mechanical perfection of the surface of the lens is of great importance, as upon it the brilliance of the image depends. An experienced eye will tell by examining the lens in a strong light whether its surfaces are as perfect as they should be.

Bubbles in the glass, on the other hand, if small and not very numerous, do not matter. In large lenses, and with many of the new Jena glasses, it is difficult to avoid them; and as the loss of light does not amount to $\frac{1}{50}$ (·02) per cent. their presence is no practical disadvantage.

STUDIO DISTANCES AND FOCI. By P. BRODIG in *British General Almanac.*

Equivalent Focus (inches).	Heights of Images (inches).																	
	1	2	3	4	6	8	10	12	14	16	20	24	28	32	40	48	56	68
2	138·0 2·0	70·0 2·1	47·3 2·1	36·0 2·1														
3	207·0 3·0	105·0 3·1	71·0 3·1	54·0 3·2	37·0 3·3													
4	276·0 4·1	140·0 4·1	94·7 4·2	72·0 4·2	49·3 4·4	38·0 4·5												
5	345·0 5·1	175·0 5·1	118·3 5·2	90·0 5·3	61·7 5·4	47·5 5·6	39·0 5·7											
6	414·0 6·1	210·0 6·2	142·0 6·3	108·0 6·4	74·0 6·5	57·0 6·7	46·8 6·9	40·0 7·1	35·1 7·2									
7	483·0 7·1	245·07 7·2	165·7 7·3	126·0 7·4	86·3 7·6	66·5 7·8	54·6 8·0	46·7 8·2	41·0 8·4	36·7 8·6								
8	552·0 8·1	280·0 8·2	189·3 8·4	144·0 8·5	98·7 8·7	76·0 8·9	62·4 9·2	53·3 9·4	46·9 9·6	42·0 9·9	35·2 10·4							
9	621·0 9·1	315·0 9·3	213·0 9·4	162·0 9·5	111·0 9·8	85·5 10·1	70·2 10·3	60·0 10·6	52·7 10·9	47·2 11·1	39·6 11·6							
10	690·0 10·1	350·0 10·3	236·7 10·4	180·0 10·6	123·3 10·9	95·0 11·2	78·0 11·5	66·7 11·8	58·6 12·1	52·5 12·4	44·0 12·9	38·3 13·5	34·3 14·1					
11	759·0 11·2	385·0 11·3	260·3 11·5	198·0 11·6	135·7 12·0	104·5 12·3	85·8 12·6	73·3 12·9	64·4 13·3	57·7 13·6	48·4 14·2	42·2 14·9	37·7 15·5	34·4 16·2				
12	828·0 12·2	420·0 12·4	284·0 12·5	216·0 12·7	148·0 13·1	114·0 13·4	93·6 13·8	80·0 14·1	70·3 14·5	63·0 14·8	52·8 15·5	46·0 16·2	41·1 16·9	37·5 17·6				
13	897·0 13·2	455·0 13·4	307·7 13·6	234·0 13·8	160·3 14·1	123·5 14·5	101·4 14·9	86·7 15·3	76·1 15·7	68·2 16·1	57·2 16·8	49·8 17·6	44·6 18·4	40·6 19·1	35·1 20·6			

Values are omitted in this space on account of the wide angle of lens required (more than ninety degrees).

14	966·0 14·2	490·0 14·4	331·3 14·6	252·0 14·8	172·7 15·2	133·0 15·6	109·2 16·1	93·3 16·5	82·0 16·9	73·5 17·3	61·6 18·0	53·7 18·9	48·0 19·8	43·7 20·6	37·8 22·2			
16	1104 16·2	560·0 16·5	378·7 16·7	288·0 16·9	197·3 17·4	152·0 17·9	124·8 18·4	106·7 18·8	93·7 19·3	84·0 19·8	70·4 20·7	61·3 21·6	54·9 22·6	50·0 23·5	43·2 25·4	38·7 27·3	35·4 29·2	
18	1242 18·3	630·0 18·5	426·0 18·8	324·0 19·1	222·0 19·6	171·0 20·1	140·4 20·6	120·0 21·2	105·4 21·7	94·5 22·2	79·2 23·3	69·0 24·4	61·7 25·4	56·2 26·5	48·6 28·6	43·5 30·7	39·9 32·8	36·0 36·0
20	1380 20·3	700·0 20·6	473·3 20·9	360·0 21·2	246·7 21·8	190·0 22·4	156·0 22·9	133·3 23·5	117·1 24·1	105·0 24·7	88·0 25·9	76·7 27·1	68·6 28·2	62·5 29·4	54·0 31·8	48·3 34·1	44·3 36·5	40·0 40·0
22	1518 22·3	770·0 22·6	520·7 23·0	396·0 23·3	271·3 23·9	209·0 24·6	171·6 25·2	146·7 25·9	128·9 26·5	115·5 27·2	96·8 28·5	84·3 29·8	75·4 31·1	68·7 32·4	59·4 34·9	53·2 37·5	48·7 40·1	44·0 44·0
24	1656 24·4	840·0 24·7	568·0 25·1	432·0 25·4	296·0 26·1	228·0 26·8	187·2 27·5	160·0 28·2	140·6 28·9	126·0 29·6	105·6 31·1	92·0 32·5	82·3 33·9	75·0 35·3	64·8 38·1	58·0 40·9	53·1 43·8	48·0 48·0
26	1794 26·4	910·0 26·8	615·3 27·1	468·0 27·5	320·6 28·3	247·0 29·0	202·8 29·8	173·3 30·6	152·3 31·3	136·5 32·1	114·4 33·6	99·7 35·2	89·1 36·7	81·2 38·2	70·2 41·3	62·8 44·4	57·6 47·4	52·0 52·0
28	1932 28·4	980·0 28·8	662·7 29·2	504·0 29·6	345·3 30·5	266·0 31·3	218·4 32·1	186·7 32·9	164·0 33·8	147·0 34·6	123·2 36·2	107·3 37·9	96·0 39·5	87·5 41·2	75·6 44·5	67·7 47·8	62·0 51·1	56·0 56·0
32	2208 32·5	1120 32·9	757·3 33·4	576·0 33·9	394·7 34·8	304·0 35·8	249·6 36·7	213·3 37·6	187·4 38·6	168·0 39·5	140·8 41·4	122·7 43·3	109·7 45·2	100·0 47·1	86·4 50·8	77·3 54·6	70·9 58·4	64·0 64·0
36	2484 36·5	1260 37·1	852·0 37·6	648·0 38·1	444·0 39·2	342·0 40·2	280·8 41·3	240·0 42·4	210·9 43·4	189·0 44·5	158·4 46·6	138·0 48·7	123·4 50·8	112·5 52·9	97·2 57·2	87·0 61·4	79·7 65·6	72·0 72·0
44	3036 44·6	1540 45·3	1041 45·9	792·0 46·6	542·7 47·9	418·0 49·2	343·2 50·5	293·3 51·8	257·7 53·1	231·0 54·3	193·6 56·9	168·7 59·6	150·9 62·1	137·5 64·7	118·8 69·9	106·3 75·1	97·4 80·2	88·0 88·0
52	3588 52·8	1820 53·5	1231 54·3	936·0 55·1	641·3 56·6	494·0 58·1	405·6 59·6	346·7 61·2	304·6 62·7	273·0 64·2	228·8 67·3	199·3 70·4	178·3 73·4	162·5 76·5	140·4 82·6	125·7 88·7	115·1 94·8	104·0 104·0

This table gives, in inches, the distances from lens to object (greater conjugate focus, upper number) and from lens to ground glass (lesser conjugate focus, lower number) for different heights of images and different lengths of foci of lenses, when the height of object is 68 ins. (=average height of man).

EXAMPLES.

Q.—What is the height of image of a person who is 133 ins. distant from lens, when a lens of 14 ins. focus is used?

A.—The height of image in this case is 8 ins.

Q.—What are the distances between object, lens, and ground glass if the image of a person is to be 8 ins. high and a 14 ins. focus lens is employed?

A.—The distance from object to lens will be 133 ins., from lens to ground glass 15·6 ins.

USEFUL FORMULÆ—*continued.*

REPRODUCING TO SCALE.

D Lens to object.
d Lens to plate.
F Focal length.
r Times of enlargement or reduction.

$$D = Fr + F.$$

$$d = \frac{E}{r} + F.$$

To find focal length necessary to give a certain reduction (r) at known distance (D).

$$F = \frac{D}{r+1}.$$

Thus, to reproduce object at 30 ft. $\frac{1}{20}$ inch size, focal length must be $\frac{30 \times 12}{20+1} = 17\frac{1}{7}$ inches.

These two formulæ used in conjunction with those on p. 25 will enable the photographer to calculate the size of image of any object at any distance. He will thus be able to work out the focal length of lenses required in a studio of given length for any given class of work.

ILLUSTRATION SHOWING THE COVERING POWER OF A MODERN ANASTIGMAT.

King Henry VII.'s Chapel, Westminster Abbey.

Original taken by W. Rice on whole plate with Goerz Double Anastigmat No. 1, at $f/31$ (the 5×4 lens of 6-in. focus).

The lens was raised about one inch from the centre, thus showing a covering power of more than 90 degrees.

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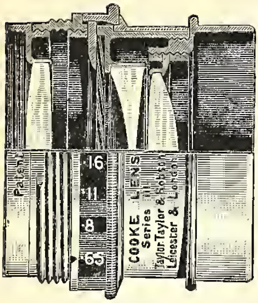

Series III.
f/6·5

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AND
SIMPLEST
ANASTIGMATS.

COOKE LENS
Series V.
f/8

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with full aperture, give critically fine definition right up to the margins of their plates, and will cover larger plates, as wide angle lenses, when stopped down.

They are free from distortion, from spherical and chromatic aberrations, from astigmatism and curved field, from flare, ghost, and other common defects of lenses.

They are nicely proportioned, more accurately made, and better finished than any other lenses.

They are more compact, and weigh much less than other anastigmats, and cost less.

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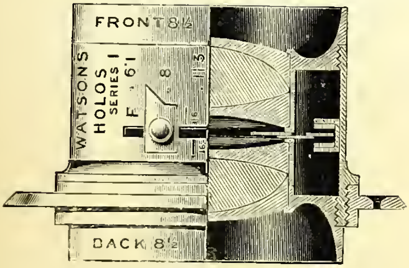

BRITISH MANUFACTURE.

An Universal Lens, extremely rapid, absolutely achromatic, free from astigmatism or distortion, and possessing magnificent defining power.

Perfect either as Doublets at f/6·1 or as Single Combinations f/11·5.

UNEQUALLED IN PERFORMANCE.
MODERATE IN COST.

No.	Single Lenses. Aperture *f*/11·5. Focus of Front.	Single Lenses. Aperture *f*/11·5. Focus of Back.	Combined Focus.	Working Aperture.	Size of Plate.	Covering with Medium Stop.	Prices with Iris Diaphragm. £	s.	d.
	ins.	ins.	ins.		ins.	ins.			
1	7¼	6	4	*f*/6·5	4 × 3	5 × 4	4	10	0
2	7¼	7¼	4¼	*f*/6·1	4¼ × 3¼	5½ × 4½	5	0	0
3	8½	7¼	4½	*f*/6·5	4½ × 4½	6 × 4½	5	10	0
4	8½	8½	5	*f*/6·1	5 × 4	6½ × 4¾	6	0	0
5	10¼	8½	5½	*f*/6·5	5½ × 4½	7 × 5	6	7	6
6	10¼	10¼	6	*f*/6·1	6 × 5	8 × 6	6	15	0
7	12¼	10¼	6½	*f*/6·5	6½ × 4¾	8½ × 6½	7	5	0
8	12¼	12¼	7	*f*/6·1	7 × 5	9 × 7	7	15	0
9	14½	12¼	7¾	*f*/6·5	8 × 6	10 × 8	8	12	6
10	14½	14½	8½	*f*/6·1	8½ × 6½	11 × 9	9	10	0
11	17¼	14½	9¼	*f*/6·5	9 × 7	12 × 10	11	15	0
12	17¼	17¼	10	*f*/6·1	10 × 8	13 × 11	14	0	0
13	20½	17¼	11	*f*/6·5	11 × 9	14 × 11	16	0	0
14	20½	20½	12	*f*/6·1	12 × 10	15 × 12	18	0	0
15	24½	20½	13	*f*/6·5	13 × 11	16 × 13	21	0	0
16	24½	24½	14	*f*/6·1	15 × 12	18 × 16	24	0	0

The above Prices are subject to a Cash Discount of 5 per cent.

Sir Wm. Huggins, F.R.S., writing on January 14th, says :—"I have tried the Holostigmat Lens, "which I find very satisfactory, and superior to the Lens I have been using."

THE PHOTOGRAM, Feb. 1902, reporting from the results of tests, says:—"The field over the "plate the lens is sold to cover (5×4 ins.) is flat and quite free from astigmatism and spherical aber-"ration. . . . . Altogether, the 'Holostigmat' is evidently well able to compete in excellence of per-"formance with any of its peers, and is come to take its place among the standard optical equipments."

PHOTOGRAPHY, July 18th, 1901, speaking of tests made with a half-plate Lens, says :—"With this stop (*f*/6·4) it could be got to cover a *whole* plate easily with good definition and on a "10×8 *only the extreme* corners were unilluminated . . . . while in the matter of distortion the "image of a straight line falling right upon the margin of the plate did not vary from the straight "more than $\frac{1}{100}$th of an inch in its whole course. *We could not wish to own a better instrument.*"

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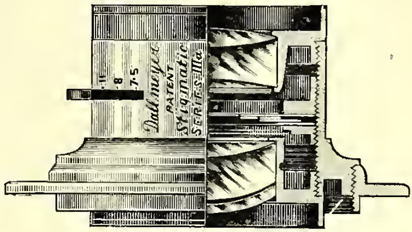
THE DALLMEYER STIGMATIC LENSES

(PATENT).

■ ■ ■ ■ ■

SERIES III.—NEW RAPID LENS.



The Series III. Stigmatics have a full aperture of *f*/7·5, and at this intensity cover the plate for which they are scheduled to the corners, while with an aperture of *f*/16 absolute definition is obtained over a plate two sizes larger. They are, for any given size of plate, much lighter and more portable than those of Series II., there being only four elements in each instead of five, as in the preceding series.

The Lenses of Series III. are not convertible, and should always be used intact.

The smaller sizes are very suitable for Hand Camera and Stereoscopic work, while the larger ones are destined to supersede the Rapid Rectilinear, their cost being only slightly in excess of the latter.

No.	Equivalent Focal Length.	Covers sharply at *f*/7·5.	Covers sharply at *f*/16.	PRICE, with Iris Diaphragms.
IAA	3 In.	2½ × 2	4¼ × 3¼	£3 0 0
IA	4	3½ × 2½	5 × 4	3 15 0
I	5	4¼ × 3¼	6½ × 1¾	3 17 6
2	6	5 × 4	7½ × 5	4 15 0
3	8¼	6½ × 4¾	8½ × 6½	5 15 0
4	9½	8 × 5	10 × 8	6 15 0
5	11	8½ × 6½	12 × 10	8 8 0
6 (*f*/8)	13	10 × 8	15 × 12	10 10 0
7 (*f*/8)	15¾	12 × 10	18 × 16	14 0 0

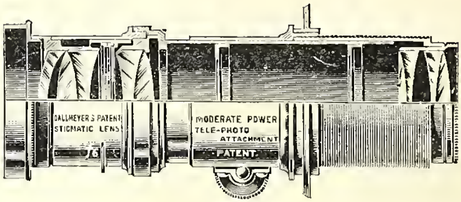
The smaller sizes of Series II. and III. may be had in pairs for Stereo. work at an additional cost of 8/- per pair nett.

J. H. DALLMEYER, Ltd.,

25 NEWMAN STREET, OXFORD STREET, LONDON, W.

COMPLETE CATALOGUE ON APPLICATION.

DALLMEYER'S TELEPHOTOGRAPHIC LENSES.



SERIES I.—HIGH POWER.

Consisting of a Portrait Lens and a high-power Negative of about one-fourth the focal length of Portrait Lens.

		Mounted in Brass.	Mounted in Aluminium.
No. 1.	PATENT STEREO LENS, with Iris Diaphragms, and No. 1 Negative (1·6 in. focus)	**£7 15 0**	**£9 5 0**
No. 2.	1 B PATENT PORTRAIT LENS, with Iris Diaphragms, and No. 2 Negative (1·8 in. focus)	**11 10 0**	**13 7 6**
No. 3.	2 B PATENT PORTRAIT LENS, with Iris Diaphragms, and No. 3 Negative (2·4 in. focus)	**18 17 6**	**21 2 6**

The negative elements alone can be adapted to any existing Patent Stereo, 1 B or 2 B Patent Portrait Lenses at the following prices:—

No. 1.	NEGATIVE	In Brass	**£2 15 0**	In Aluminium	**£3 5 0**
No. 2.	,, ...	,,	**3 15 0**	,,	**4 7 6**
No. 3.	,, ...	,,	**4 17 6**	,,	**5 12 6**

■ ■ ■ ■ ■

SERIES II.—MODERATE POWER.

Consisting of a Portrait Lens and a Moderate Power Negative of about half the focal length of Portrait Lens.

		Mounted in Brass.	Mounted in Aluminium.
No. 1.	PATENT STEREO LENS, with Iris Diaphragms, 2½ in. focus negative	**£8 10 0**	**£10 0 0**
No. 2.	1 B PATENT PORTRAIT LENS, with Iris Diaphragms, and 3 in. focus negative	**11 5 0**	**13 2 6**
No. 3.	2 B PATENT PORTRAIT LENS, with Iris Diaphragms, and 4 in. focus negative	**18 5 0**	**20 10 0**

The negative elements alone can be adapted to any existing Patent Stereo, 1 B or 2 B Patent, or similar Portrait Lenses at the following prices:—

2½ in.	NEGATIVE	In Brass	**£3 10 0**	In Aluminium	**£4 0 0**
3 in.	,, ...	,,	**3 10 0**	,,	**4 2 6**
4 in.	,, ...	,,	**4 5 0**	,,	**5 0 0**

Prices of larger sizes on application.

SERIES I. and II. combined.—In this case the same Portrait Lens is utilised, and an adjustable mount fitted, capable of carrying both a high and a moderate power negative, which are supplied.

J. H. DALLMEYER, Ltd.,

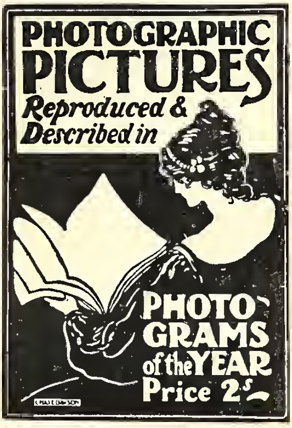
25 NEWMAN STREET, OXFORD STREET, LONDON, W.

COMPLETE CATALOGUE ON APPLICATION.

LEADING LENS MAKERS

are always willing to help and advise the users of their instruments; certain of them retain a staff for this purpose. All the makers mentioned in this book possess a copy of *The Lens*, and it will help both them and us if readers addressing queries to them will say that they also have *The Lens.* The makers can then refer to some paragraph which will throw light on the problem.

PHOTOGRAMS OF THE YEAR.



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